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Environmental Assessment of a Low-Emission Oil-Fired Residential Hot Water Condensing Heating System. Volume I: Technical Results

Acurex Corp.
Mountain View, CA

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

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A LOW-EMISSION OIL-FIRED
RESIDENTIAL HOT WATER
CONDENSING HEATING SYSTEM
Volume I. Technical Results

Prepared for

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16. ABSTRACT The report gives results of a test program measuring air and water emissions from a high-efficiency hot-water residential heating system of European design, utilizing a condensing flue gas system and a low emission burner. Criteria and noncriteria emissions, including trace elements and organic species in both flue gas and condensate waste water streams, were measured. NO (as NO2), CO, total UHC (as propane), and total particulate emissions measured about 37, 12, 1.5, and 2.7 ng/J heat input, respectively. Absorption of sulfates and nitrates in the waste water resulted in a constant pH of 3.0. Total organic emissions in the flue gas measured 3.5 mg/dscm; they were below the detectable limit in the waste water. Several inorganic trace elements, including chromium, copper, iron, and nickel, in the waste water were attributed to leaching of heat transfer metal surfaces by the warm acidic water. Bioassays were also performed to evaluate the potential health hazard of the streams. Results indicate nondetectable to moderate toxicity and mutagenicity.

17. KEY WORDS AND DOCUMENT ANALYSIS

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ENVIRONMENTAL ASSESSMENT OF A LOW-EMISSION OIL-FIRED RESIDENTIAL HOT WATER CONDENSING HEATING SYSTEM

Volume I: TECHNICAL RESULTS

Acurex Project 7600
Contract 68-02-3188

for

EPA Project Officer – R. E. Hall
Combustion Research Branch
Energy Assessment and Control Division
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NOTICE

Mention of trade names or commercial products does not consititute endorsement or recommendation for use.

CONTENTS

Figures iv
Tables v
Acknowledgements vi

1. Executive Summary 1
   1.1 Residential Heater 1
   1.2 Furnace Operation and Test Arrangement 4
   1.3 Emission Measurements and Results 5
   References for Section 1 15
2. Introduction 16
   References for Section 2 24
3. Source Description 25
   References for Section 3 31
4. Emissions Results 32
   4.1 Furnace Operation and Test Arrangement 32
   4.2 Flue Gas and Water Emissions 34
   References for Section 4 58
5. Environmental Assessment 59
   5.1 Source Analysis Model Evaluations 59
   5.2 Bioassay Analysis. 64
   References for Section 5 65

Appendices

A. Test Equipment and Procedures 66
B. Trace Element Concentrations 82
C. Conversion Factors. 92

FIGURES

Number		Page
1-1	Residential Hot Water Heater Equipped with Low-Emission Distillate Oil-Fired Burner	2
1-2	Schematic of the M.A.N. Residual Oil-Fired Burner	3
1-3	Hot Water Residential Heating System Cycle Temperature Profiles.	7
1-4	Gas Sampling Location	8
3-1	Residential Hot Water Heater Equipped With Low-Emission Distillate Oil-Fired Burner	26
3-2	Schematic of the M.A.N. Residential Oil-Fired Burner	27
3-3	Schematic of the Hot Water Tank	29
3-4	Heat Exchanger Assembly	30
4-1	Hot Water Residential Heater Temperature Profiles	36
4-2	Gas Sampling Locations	38
4-3	Strip Chart Recordings of Emissions During a Typical Burner Cycle	40

TABLES

1-1	Hot Water Residential Heating System Test Operating Conditions	6
1-2	Summary of Flue Gas and Water Emissions	10
1-3	Organic Extract Summary -- XAD-2 Sorbent Extract	12
1-4	Bioassay Analysis Results	14
2-1	Completed Tests During the Current Program	20
4-1	Hot Water Residential Heating Systems Test Operating Conditions	35
4-2	Flue Gas Emissions	39
4-3	Ultimate Fuel Analysis of Distillate Oil	42

TABLES (CONCLUDED)

Number		Page
4-4	Trace Element Emissions	44
4-5	C_1 to C_6 Flue Gas Hydrocarbon Analysis	48
4-6	Results of TCO and Gravimetric Analyses of Total Extract Samples	50
4-7	Summary of Infrared Spectrometry Analysis of Total Extract Samples	51
4-8	Gravimetric and TCO Results of Column Chromatography of the XAD-2 Samples	52
4-9	Infrared Analysis of Column Chromatography Fractions	53
4-10	Organic Extract Summary -- XAD-2 Sorbent Extract	54
4-11	Compounds Sought in GC/MS Analysis and Their Detection	
4-12	Results of Quantification of POM Compounds	57
5-1	Flue Gas and Water Discharge Severities (Health-Based) Greater than 0.1 for the Hadwick Furnace Equipped with Low-NO_x M.A.N. Burner	61
5-2	Bioassay Analysis Results	63

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SECTION 1

EXECUTIVE SUMMARY

This report describes emission results obtained from laboratory testing of flue gas and liquid streams from a residential hot water heater burning distillate oil. This work was performed for the Industrial Environmental Research Laboratory (IERL) of the Environmental Protection Agency (EPA) under the Combustion Modification Environmental Assessment (CMEA) program, EPA contract No. 68-02-3188. The primary objective of the tests was to measure flue gas and liquid emissions and to evaluate the operating efficiency of the heater under simulated domestic operation in the laboratory.

1.1 RESIDENTIAL HEATER

The residential heater tested in this program represents an innovative European design utilizing a condensing flue gas system and a high efficiency low-NO_x burner. The heater, illustrated in figure 1-1, is targeted for the commercial and residential North American market through Karlsons Blueburner Systems Ltd. of Canada. The burner, illustrated in figure 1-2, is manufactured by Maschinenfabrik Augsburg-Nurnberg (M.A.N.) of West Germany. The burner utilizes a finely atomized oil and recirculated hot combustion gases mixed with fresh air to complete combustion of the fuel in the burner pipe. The combustion of the fuel in the mixing tube produces a stable "blue flame" which has become the trademark of this

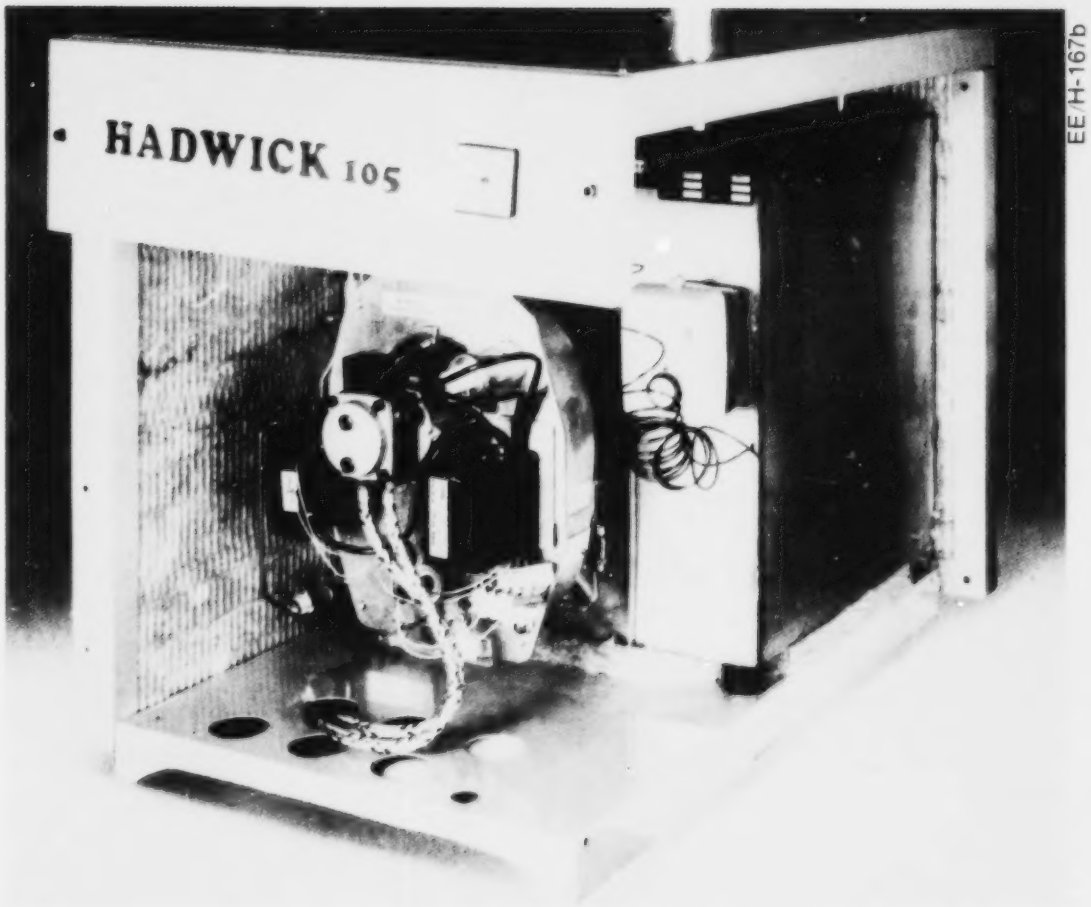

Figure 1-1. Residential Hot Water Heater Equipped With Low-Emission Distillate Oil-Fired Burner (reference 1-1)

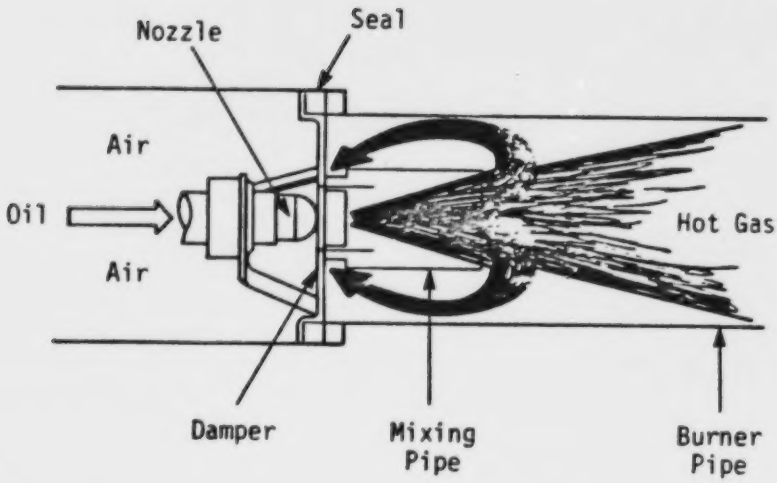

Figure 1-2. Schematic of the M.A.N. Residual Oil-Fired Burner

burner design. The recirculation of the combustion gases also causes NO_x emissions to be 40 to 50 percent lower than those from a conventional high-pressure atomizing burner widely used for residential oil-fired furnaces.

The firebox is completely immersed in water. Combustion products pass over the tank water surface and through a series of baffles and heat exchanger tubes before they exit the furnace exhaust duct. The cooling water, which serves to absorb the heat from the furnace and carry it to the residence, enters through a heat exchanger tube located near the top of the furnace and then goes through the immersed copper coils before it exits. Condensation of the flue gas moisture begins when cool water meets combustion products on their way out of the tank, condensing practically all the water produced by combustion of the fuel.

1.2 FURNACE OPERATION AND TEST ARRANGEMENT

The test program called for the analysis of discharged water as well as flue gas samples. Therefore, prior to the start of the test, the interior surfaces of the water tank and cooling coils were subjected to rigorous cleaning to remove all traces of solid organic and inorganic material which might contaminate the initial water charge and lead to erroneous conclusions. Following the cleaning, the tank was filled with municipal tap water. A tap water sample from the tank was then collected and used as a blank for all analyses of water discharge samples.

The tank water was then subjected to approximately one week of conditioning to simulate as-found heater operation. Conditioning took place by operating the heater in a cyclic mode (approximately 10 min burner on, 20 min burner off), similar to the cycle that was implemented during the test. After a week of cyclic firing, the pH of the tank

reached a constant value of about 3.0. At that point, a tank water sample was collected to be analyzed for anions, trace elements, and organic concentrations.

An electronic data logger (Autodata 8) was used to record minute-by-minute temperature readings of ambient air, stack flue gas, inlet water, outlet water, and tank water during both burner-on and burner-off periods. Table 1-1 summarizes heater settings and operating conditions during the test. Figure 1-3 illustrates temperature profiles recorded during a typical burner-on/burner-off cycle. The entire test period included 19 such cycles for a total test time of 242 min.

The thermal efficiency of the heater calculated from the heat output (the area in figure 1-3 between water-out and water-in temperatures), water flowrate, and heat input (total fuel used during the test) measured 101 percent. Because measurements of water flowrate and total fuel used are not considered accurate to three significant figures, the efficiency of the unit may have been slightly overestimated, as the greater than 100 percent would indicate. However, it is safe to say that the thermal efficiency of this condensing system is essentially 100 percent as indicated by measurements of flue gas temperatures which were often lower than combustion air temperatures.

1.3 EMISSION MEASUREMENTS AND RESULTS

Flue gas measurements were made at the exit of the furnace at approximately 1m (3 ft) from the base of the uninsulated exhaust pipe as shown in figure 1-4. Flue gas measurements included:

Table 1-1. Hot Water Residential Heating System
Test Operating Conditions

- M.A.N. burner operating conditions:

-- Burner oil pressure	1.03 MPa (150 psig)
-- Oil temperature	ambient
-- Burner on-time	11 to 14 min
-- Burner off-time	22 to 25 min
-- Distillate oil flow	0.45 ml/sec (0.49 gal/hr)

- Hot water heating system initial settings and operating conditions:

-- Tank water capacity	56.8 l (15 gal)
-- Tank water at start of test	53.0 l (14 gal)
-- Cooling water flow	107 ml/s (1.7 gal/min)
-- Tank water thermostat setting	54 to 55°C (129 to 131°F)
-- Average inlet water temperature	13°C (56°F)
-- Average rise of outlet water temperature	19°C (35°F)
-- Average rise of tank water temperature	32°C (58°F)
-- pH of tank water	2.7
-- Approximate tank water discharge rate	0.47 ml/s (0.43 gal/hr)
-- Flue gas temperature	16.7 to 27.8°C (62 to 82°F)

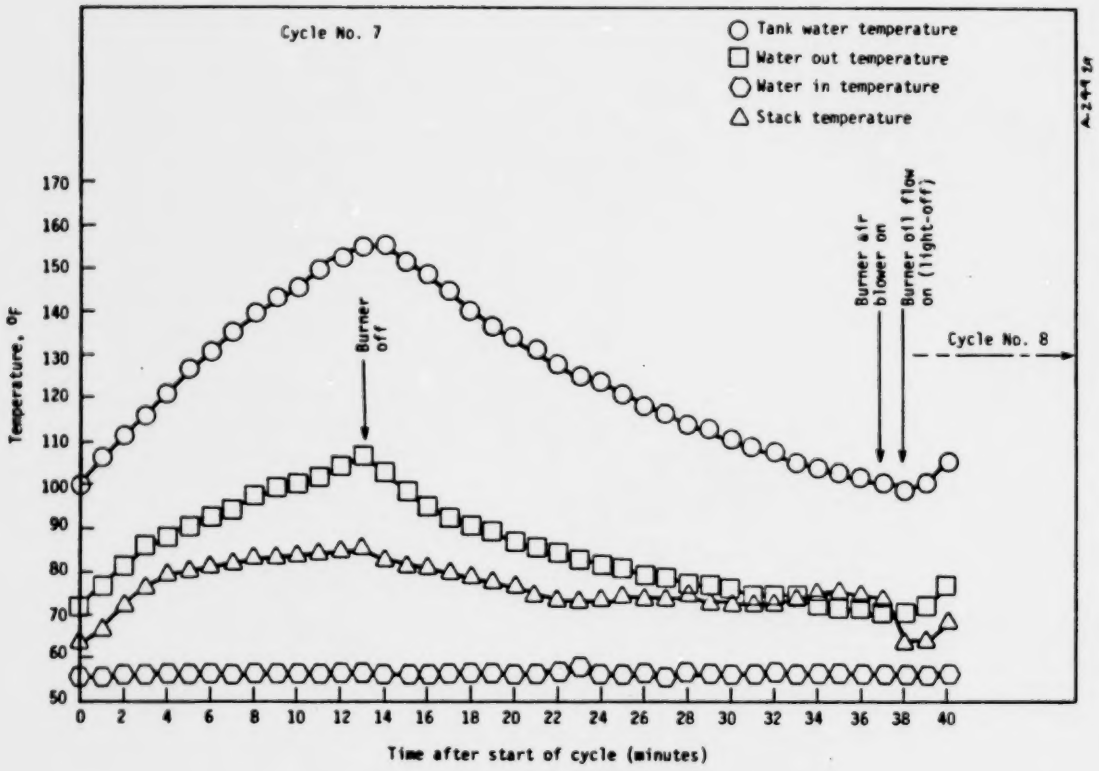

Figure 1-3. Hot Water Residential Heating System Cycle Temperature Profiles

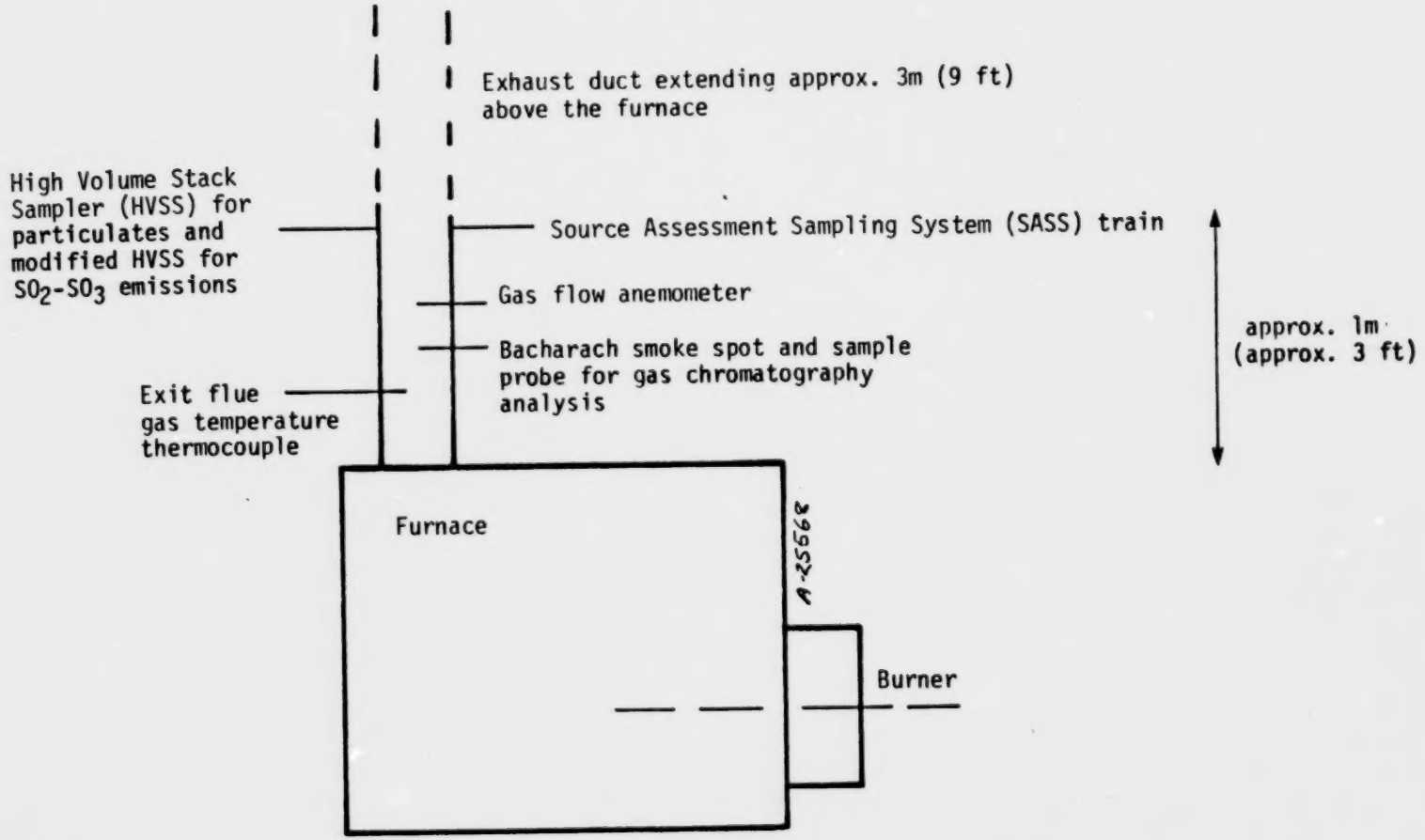
Exhaust duct extending approx. 3m (9 ft) above the furnace
High Volume Stack Sampler (HVSS) for particulates and modified HVSS for SO_2-SO_3 emissions
Source Assessment Sampling System (SASS) train
Gas flow anemometer
Bacharach smoke spot and sample probe for gas chromatography analysis
Exit flue gas temperature thermocouple
approx. 1m (approx. 3 ft)
Furnace
A-25568
Burner

Figure 1-4. Gas Sampling Location

- Continuous monitoring for NO_x, NO, CO, CO_2, O_2, and TUHC
- Source Assessment Sampling System (SASS) for trace elements and organic emissions
- EPA Method 5 for solid and condensable particulate mass emissions
- EPA Method 8 for sulfur species (SO_2, SO_3)
- Grab sample for onsite analyses of C_1 - C_6 hydrocarbons by gas chromatography
- Bacharach smoke spot

Water samples at the end of the test were collected for laboratory analysis of trace elements, organics, and anions. Bioassay tests were also performed on the extract of the organic sorbent in the SASS and for the water sample at the end of the test to estimate the potential toxicity and mutagenicity to mammalian organisms.

Table 1-2 summarizes both flue gas and water emissions measured in the test program. Emissions are presented in nanograms per Joule heat input (ng/J) and in terms of their respective potential health hazard. The potential health hazard is given by the Discharge Severity (DS) which is defined as the ratio of the concentration of a pollutant to an appropriate Discharge Multimedia Environmental Goal (DMEG). DMEG values were developed by EPA for use in Environmental Assessment programs. They correspond to maximum pollutant concentrations considered safe for short term exposure (reference 1-2, 1-3). A DS greater than 1.0 suggests a potential hazard, and more refined chemical analysis may be required to quantify specific compounds present. Table 1-2 lists criteria emissions measured in the gas stream and trace elements in both gas and liquid streams for which the health-based DS exceeded 0.1.

Table 1-2. Summary of Flue Gas and Water Emissions

Compound	Flue Gas		Waste Water	
	Average Concentration (ng/J)	DS (ND)	Average Concentration (ng/J)	DS (ND)
Criteria Pollutant and Other Vapor Phase Emissions				
CO	11.9	7.7×10^{-1}	--[c]	--
NO (as NO_2)	37.1	1.1×10^{1}	--	--
NO_2	0	--	--	--
TUHC (as C_3H_8)	1.5	1.2×10^{-3}	--	--
SO_2	106.3	1.0×10^{1}	--	--
SO_3 (vapor)	0	--	--	--
Solid particulate	1.3	NA[d]	--	--
Condensable particulate	1.4	NA	--	--
Smoke	0	--	--	--
Organic Categories				
Aldehydes	3.8×10^{-5}	0.40	--	--
Carboxylic acid	7.6×10^{-5}	0.20	--	--
Trace Elements & Anions				
Copper, Cu	2.2×10^{-3}	3.0×10^{-2}	1.1×10^{1}	100
$SO_4^{=}$ (condensed)	--	--	2.2×10^{1}	67
$NO_3^{=}$ (condensed)	--	--	1.5×10^{-1}	9.3×10^{-2}
Chloride, Cl^-	--	--	2.2×10^{-2}	1.7×10^{-1}
Chromium, Cr	1.3×10^{-3}	3.4	1.1×10^{-1}	2.8
Iron, Fe	5.9×10^{-3}	2.1×10^{-2}	1.6×10^{-1}	6.7
Lead, Pb	1.1×10^{-3}	1.9×10^{-2}	1.3×10^{-3}	2.8×10^{-1}
Manganese, Mn	5.2×10^{-4}	2.8×10^{-4}	2.2×10^{-3}	7.6×10^{-1}
Nickel, Ni	3.3×10^{-3}	5.7×10^{-1}	1.6×10^{-2}	4.4
Selenium, Se	9.6×10^{-5}	1.3×10^{-3}	2.2×10^{-3}	2.0
Sodium, Na	$>8.0 \times 10^{-2}$	$>1.1 \times 10^{-1}$	--	--
Sulfur, S	1.8×10^{-1}	4.8×10^{-1}	--	--
Zinc, Zn	2.9×10^{-3}	1.9×10^{-3}	$>2.2 \times 10^{-1}$	$>4.0 \times 10^{-1}$
Total Discharge Severity (TDS)	--	27.0	--	185
Weighted Discharge Severity (WDS), g/s	--	2,600	--	8.7

[a] Flue gas O_2 and CO_2 concentrations are 1.9 and 12.9 percent respectively, dry basis

[b] ND = nondimensional

[c] Dashes indicate that pollutant was not sought in the analysis or was below detectable limit

[d] NA = not applicable

For the flue gas stream, NO and SO_2 emissions were responsible for the highest DS values, both exceeding unity by nearly a factor of 10. CO and total hydrocarbons were present at concentrations posing less concern (DS less than 1.0). Four elements with DS greater than 0.1 were found in the flue gas. These were chromium, nickel, sodium, and sulfur, with only chromium having a DS exceeding unity. Both chromium and nickel can be introduced as contaminants in sample preparation procedures prior to Spark Source Mass Spectrometry (SSMS) analysis.

Total organic emissions in the flue gas measured 3.5 mg/dscm. Infrared spectrometry (IR) and Low Resolution Mass Spectrometry (LRMS) indicated that the organic matter consisted primarily of aliphatic hydrocarbons (about 90 percent), alcohols (about 4 percent), and carboxylic acids, esters, ketones, or amines (about 5 percent). Table 1-3 summarizes these organic emission results for the flue gas. The DS values shown in table 1-2 were calculated assuming the levels shown in table 1-3 consisted entirely of the compound with the lowest DMEG potentially present in the respective MEG category. In this respect, the organic category DS values in table 1-3 represent conservative upper bounds.

Organic matter in the waste water was found to be at concentrations less than detectable. Gas Chromatography/Mass Spectrometry (GC/MS) analysis of the organic sorbent extract showed the presence of anthracene/phenanthrene and naphthalene in nonhazardous concentrations ranging from 2 to 36 µg/dscm.

Trace elements in the tank water for which DS exceeded unity were copper, chromium, iron, nickel, and selenium. Copper levels significantly exceeded those of any other trace element. This was probably caused by

Table 1-3. Organic Extract Summary -- XAD-2 Sorbent Extract

	LC1	LC2	LC3	LC4	LC5	LC6	LC7	$\sum$
Total Organics, mg	75	2	<3	<2	<2	2	4	85
TCO, mg	52	0.2	<0.85	<0.1	<0.02	<0.02	<0.02	54
GRAV, mg	23	2	<2	<2	<2	2	4	31

Category	Assigned Intensity -- mg/dscm							
	LC1	LC2	LC3	LC4	LC5	LC6	LC7	
Aliphatic HCs	100--2.6							2.6
Aldehydes			100-<0.11					0.11
Carboxylic Acids							100--0.14	0.14

leaching of copper coils immersed in the warm acidic water. Concentrations of copper in the 480 to 505 mg/l range were detected using the more accurate rate AA analysis versus greater than 10 mg/l reported using the SSMS analysis.

Concentrations of 1,000 mg/l of $SO_4^=$ and 7 mg/l of NO_3^- caused by dissolution of SO_3 and NO_2 in condensed water in the flue gas, resulted in acidic tank water with a pH of about 3.0. The DS for $SO_4^=$ (as H_2SO_4) is 67, the second highest after copper. Nitrate concentrations, however, are not sufficiently high to pose an environmental concern.

Total Discharge Severity (TDS), defined as the sum of all DS, for the liquid stream exceeded that of the gas stream due primarily to the copper and sulfate concentrations in the water. However, based on the total flow-rate of each stream, the exhaust gas still poses a higher environmental risk relative to the waste water as indicated by the Weighted Discharge Severity (WDS) which is defined as the TDS times the mass flowrate of the stream.

Bioassay tests were performed on the organic sorbent (XAD-2) extract and the tank water discharge -- bioassay results reported here are for health effects tests only. These tests are (1) the Ames assay, based on the property of Salmonella typhimurium mutants to revert due to exposure to various classes of mutagens; (2) the cytotoxicity assay (CHO) of mammalian cells in culture to measure cellular metabolic impairment and death resulting from exposure to soluble and particulate toxicants; and (3) acute toxicity tests in live rodents (RAT) to identify <u>in vivo</u> toxic effects of unknown compounds. The results of these assays are summarized in table 1-4 for both the flue gas sample (organic sorbent extract) and a liquid sample (tank water discharge recovered at the end of the test). The responses recorded in the biological tests varied from nondetectable to moderate toxicity and mutagenicity.

Table 1-4. Bioassay Analysis Results

Sample	Evaluation[a]		
	CHO[b]	Ames[c]	RAT[b]
Organic sorbent XAD-2	L/ND	M[c]	--
Tank water discharge	M	ND	ND

[a]ND = nondetectable toxicity/mutagenicity
L = low toxicity
M = moderate toxicity/mutagenicity

[b]Toxicity test

[c]Mutagenicity test

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1-1. "Hadwick 105," sales brochures provided by the Danish Aircraft Systems A/S, Hobrovej 180 DK 9560 Hadsund.

1-2. Cleland, J. G., and G. L. Kingsbury, "Multimedia Environmental Goals for Environmental Assessment: Volumes I and II," EPA-600/7-77-136 a, b, U.S. Environmental Protection Agency, November 1977.

1-3. Kingsbury, G. L., et al., "Multimedia Environmental Goals for Environmental Assessment: Volumes III and IV," EPA-600/7-79-176a,b, August 1979.

SECTION 2

INTRODUCTION

This report presents results of and describes environmental tests performed for the Industrial Environmental Research Laboratory (IERL) of EPA under the Combustion Modification Environmental Assessment (CMEA) program, EPA contract No. 68-02-3188. The CMEA started in 1976 as a three-year study, NO_x EA, EPA contract No. 68-02-2160, having the following five objectives:

- Determine multimedia environmental stresses from stationary combustion sources and combustion modification technology
- Develop and document control application guidelines to minimize these stresses
- Identify stationary source and combustion modification R&D priorities
- Support environmental assessment methodology development
- Disseminate program results to intended users

During the first year of the NO_x EA, data and methodologies for the environmental assessment were compiled. Furthermore, priorities for the schedule and level of effort for the various source/fuel/control combinations were identified. This effort revealed major data gaps, particularly for noncriteria pollutants (organic emissions and trace

elements) for virtually all combinations of stationary combustion sources and combustion modification techniques. Consequently, a series of seven environmental field test programs was undertaken to fill these data gaps. The results of these tests are documented in seven individual reports (references 2-1 through 2-7) and in the final NO_x EA report summarizing the entire three-year effort (reference 2-8).

The current CMEA program has, as major objectives, the continuation of multimedia environmental field tests initiated in the original NO_x EA program. These new tests, using standardized Level 1 sampling and analytical procedures (reference 2-9) are aimed at filling the remaining data gaps and addressing the following priority needs:

- Advanced NO_x controls
  - -- Evaluation of controls with regard to the impending New Source Performance Standard (NSPS)
  - -- Evaluation of controls designated Best Available Control Technology (BACT)
- Alternate fuels
- Secondary sources
- EPA program data needs
  - -- Residential oil combustion
  - -- Wood firing in residential, commercial, and industrial sources
  - -- High interest emissions determination (dioxins, radionuclides, etc.)
- Nonsteady-state operations

Residential distillate oil-fired heating systems have in recent years been the subject of intensive investigation to assess the thermal

efficiencies as well as their emissions. Results of these studies, summarized in a NO_x EA report (reference 2-10), have shown that conventional residential warm air and hot water heating systems in the field often have relatively low thermal efficiencies and that their emissions, although small on a unit-by-unit basis, can often contribute significantly to ambient air quality deterioration in urban areas during the winter season. Furthermore, laboratory analyses of flue gas samples have shown that total organic emissions measured on a heat input basis from distillate oil-fired residential heaters operating in cyclic mode can be significantly above organic emissions from other major stationary combustion source categories (reference 2-11).

A number of low-emission, high-efficiency residential heating systems/burners have been developed in recent years. In the NO_x EA program, flue gas emissions from one such low-emission, high-efficiency residential warm air furnace were evaluated (reference 2-4). During the current CMEA, two other residential heating systems have been investigated. This report presents results of a hot water domestic furnace in which the exhaust gas temperature is well below the water dew point and thus the latent heat of water in the flue gas is recovered. This condensing hot water furnace is equipped with a low emission distillate oil-fired burner developed by Maschinenfabrik Augsburg-Nurnberg (M.A.N.) and a subject of recent investigations by the IERL of the EPA. The objectives of this test program were to assess multimedia emissions in gas and liquid streams from the heater and to evaluate the operating efficiency of the unit under simulated domestic operation in the laboratory. Since this innovative domestic furnace design has not been

installed in the United States, field tests under actual field operation could not be pursued.

As mentioned earlier, concurrently with this test program, a second residential low emission and improved efficiency furnace was also tested. This furnace, developed by the Rocketdyne Division of Rockwell International under EPA sponsorship, uses a conventional design incorporating a state-of-the-art warm air furnace with modified low emission burner and firebox designs. Results of the tests on the Rocketdyne/EPA furnace are presented in a separate report (reference 2-12). Table 2-1 lists all the tests performed to date in the CMEA effort, outlining the source tested, fuel used, combustion modification controls implemented and the level of sampling and analysis performed in each case. Results of these test programs are presented in separate reports available through EPA.

Table 2-1. Completed Tests During the Current Program

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Collaborator
Spark ignited natural gas-fired reciprocating internal combustion engine	Large bore, 6 cylinder, opposed piston, 186 kW (250 Bhp)/cyl, 900 rpm Model 38TDS8-1/8	-- Baseline (pre-NSPS) -- Increased air-fuel ratio aimed at meeting proposed NSPS of 700 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Compression ignition diesel-fired reciprocating internal combustion engine	Large bore, 6 cylinder opposed piston, 261 kW (350 Bhp)/cyl, 900 rpm Model 38TDD8-1/8	-- Baseline (pre-NSPS) -- Fuel injection retard aimed at meeting proposed NSPS of 600 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 8 -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Low-NO_x residential condensing heating system furnished by Karlsons Blueburner Systems Ltd. of Canada	Residential hot water heater equipped with M.A.N. low-NO_x burner, 0.55 ml/s (0.5 gal/hr) firing capacity, condensing flue gas	Low-NO_x burner design by M.A.N.	Furnace exhaust: -- SASS -- Method 8 -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Waste water	--
Rocketdyne/EPA low-NO_x residential forced warm air furnace	Residential warm air furnace with modified high pressure burner and firebox, 0.83 ml/s (0.75 gal/hr) firing capacity	Low-NO_x burner design and integrated furnace system	Furnace exhaust: -- SASS -- Method 8 -- Controlled condensation -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel	--

Table 2-1. Continued

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Collaborator
Pulverized coal-fired utility boiler, Conesville station	400 MW tangentially fired - new NSPS design aimed at meeting 301 ng/J NO_x limit	ESP inlet and outlet - one test	ESP inlet and outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2 Coal Bottom ash ESP ash	Exxon Research and Engineering (ER&E)
Industrial boiler	1.14 kg/s steam (9,000 lb/hr) fired with a mixture of coal-oil-water (COW) 1.89 kg/s steam	-- Baseline (COW) -- Controlled SO_2 emissions with limestone injection	Boiler outlet -- SASS -- Method 5 -- Method 8 -- Controlled Condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, CO_2, CO, NO_x Fuel	Envirocon
Industrial boiler	1.89 kg/s steam (15,000 lb/hr) hot water firetube fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with Na_2CO_3 injection	Boiler outlet -- SASS -- Method 5 -- Method 8 -- Controlled Condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, CO_2 NO_x Fuel	Adelphi University
Industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a mixture of coal-oil (COM)	-- Baseline test only with COM	Boiler outlet -- SASS -- Method 5 -- Controlled Condensation -- Continuous O_2, CO_2, NO_x, TUHC, CO -- N_2O grab sample Fuel	PETC and General Electric (GE)

Table 2-1. Continued

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Collaborator
Oil refinery vertical crude oil heater	2.54 Ml/day (16,000 bbl/day) natural draft process heater burning oil/refinery gas	-- Baseline -- Staged combustion using air injection lances	Heater outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO_x, CO, CO_2, HC N_2O grab sample Fuel oil Refinery gas	KVB
Industrial boiler	8.21 kg/s steam (65,000 lb/hr) watertube burning mixture of refinery gas and residual oil	-- Baseline -- Ammonia injection using the noncatalytic Thermal DeNO$_x$ process	Economizer outlet -- SASS -- Method 5, 17 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Ammonia emissions -- N_2O grab sample -- Continuous O_2, NO_x, CO, CO_2 Fuels (refinery gas and residual oil)	--
Industrial boiler	2.52 kg/s steam (20,000 lb/hr) watertube burning wood waste	-- Baseline (dry wood) -- Wet (green) wood	Boiler outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO_x, CO Fuel Flyash	North Carolina Department of Natural Resources, EPA IERL-RTP
Industrial boiler	3.16 kg/s steam (29,000 lb/hr) firetube with refractory firebox burning wood waste	-- Baseline (dry wood)	Outlet of cyclone particulate collector -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO_x, CO Fuel Bottom ash	North Carolina Department of Natural Resources, EPA IERL-RTP

Table 2-1. Concluded

Source	Description	Test Points Unit Operation	Sampling Protocol	Test Collaborator
Enhanced oil recovery steam generator	6.31 kg/s steam (50,000 lb/hr) equipped with MHI low-NO_x burner firing crude oil	-- Emissions performance mapping -- Extended tests at "optimum" emissions performance	Exhaust duct -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1 - C_6 HC) -- N_2O grab sample -- Continuous O_2, NO_x, CO CO_2, TUHC Fuel	--

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2-3. Higginbotham, E. B. and P. M. Goldberg, "Combustion Modification NO_x Controls for Utility Boilers: Volume I -- Tangential Coal-fired Unit Field Test," EPA-600/7-81-124a, July 1981.

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2-8. Waterland, L. R. et al., "Environmental Assessment of Stationary Source NO_x Control Technologies -- Final Report," Acurex Report FR-80-57/EE, April 1980.

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2-12. DeRosier, R., "Environmental Assessment of Low Emission Oil-Fired Residential Warm Air Furnace," Acurex Draft Report No. TR-81-82/EE, July 1981.

SECTION 3

SOURCE DESCRIPTION

The residential hot water heater, illustrated in figure 3-1, combines a low-emission, high-efficiency distillate oil-fired burner with a condensing heat exchanger. The burner, manufactured by M.A.N., utilizes blue flame combustion technology developed by Professor Buschulte of the German Research and Testing Laboratory for Air and Space Travel (DFVLR). Its design produces NO_x emission levels which are normally 40 to 50 percent below those from conventional residential oil-fired high-pressure atomizing burners.

The burner, illustrated in figure 3-2, utilizes finely atomized oil and recirculated hot combustion gases mixed with fresh air to complete the combustion of the fuel in the burner pipe. The fuel oil can be pressurized to 2.1 MPa (approximately 300 psi) and is atomized by a 60^{o} hollow cone nozzle delivering about 0.53 ml/s (0.5 gal/hr). The combustion of the fuel in the mixing tube produces a stable blue flame which has become the trademark of this burner design. Because the M.A.N. burner recirculates the combustion gases internally within the burner pipe where combustion is completed, retrofit installation on existing residential heating systems is possible. Although other blue flame burner designs have been developed and implemented in the United States (reference 3-2), the retrofit capability of the M.A.N. design has made it

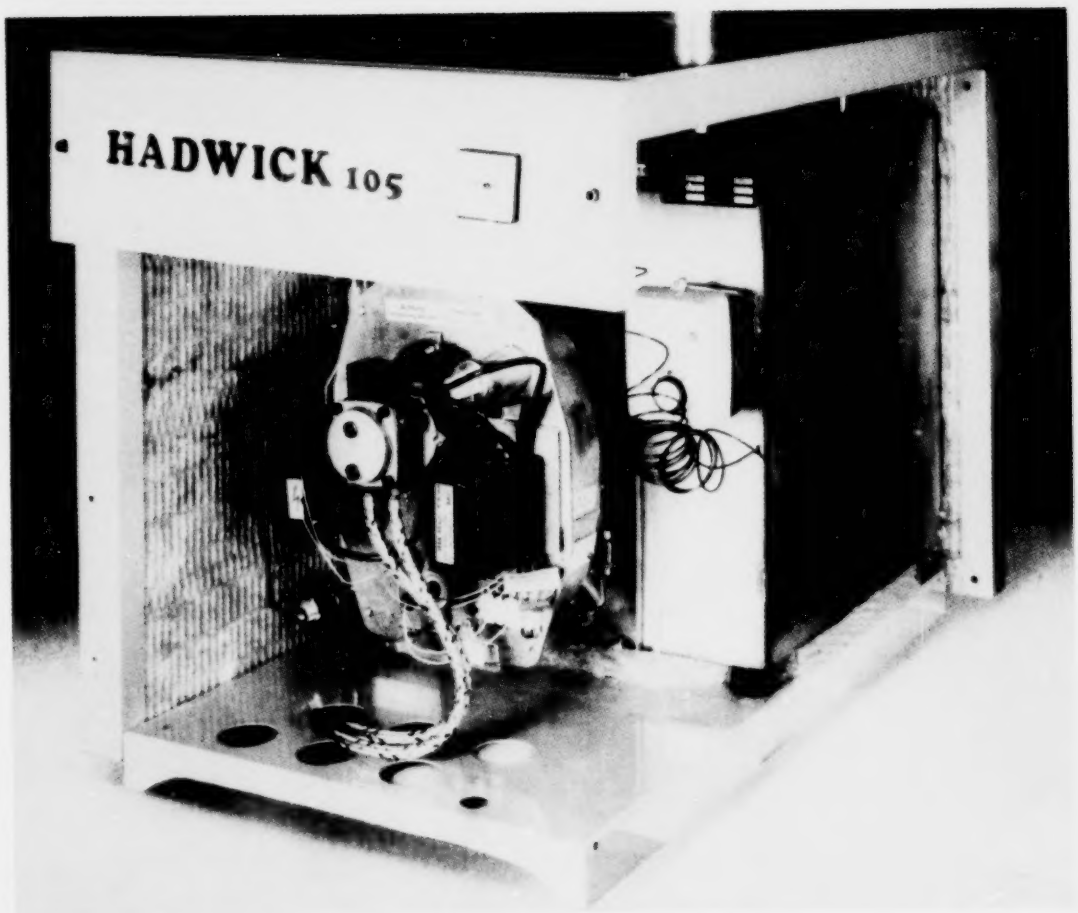

Figure 3-1. Residential Hot Water Heater Equipped With Low-Emission Distillate Oil-Fired Burner (reference 3-1)

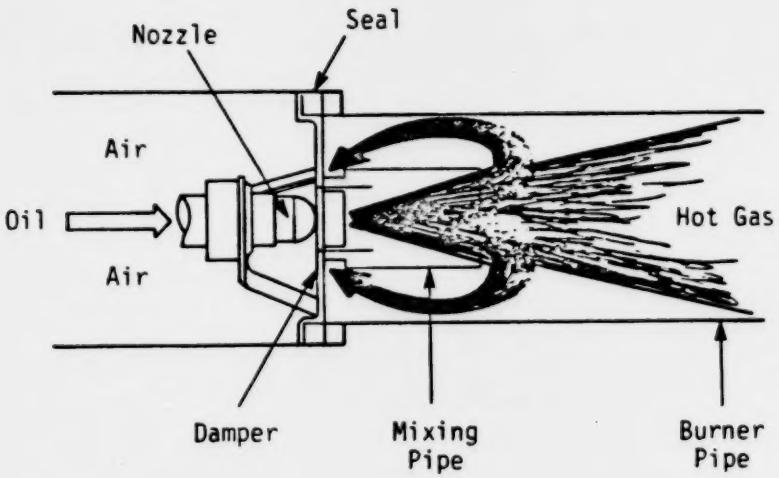

Figure 3-2. Schematic of the M.A.N. Residential Oil-Fired Burner

attractive as a potential technique for reducing NO_x emissions from existing residential units.

Figures 3-3 and 3-4 illustrate the hot water tank and heat exchanger assembly, respectively. The firebox, shown in figure 3-3 is completely immersed in water. The water level reaches approximately 2 cm (less than one inch) below the top of the three exhaust pipes. This water level is controlled by positioning the condensed water drain spout. Before the combustion products exit the furnace exhaust duct, they pass over the water surface and through a series of baffles and heat exchanger tubes. The baffle and heat exchanger tubes configuration is illustrated in figure 3-4.

The cooling water, which serves to absorb the heat from the furnace and carry it to the residence, enters through a heat exchanger tube located near the top of the furnace and then goes through the immersed copper coils before it exits. Condensation of the water in the flue gas begins when cool water meets combustion products on their way out of the tank, condensing practically all the water produced by combustion of the fuel.

Condensing heating systems for domestic hot water or warm air have been proposed as a means of reducing residential fuel consumption (reference 3-4). The Hadwick 105 furnace tested during this program represents one such condensing heating design where combustion efficiencies exceeding 95 percent under normal cyclic operation can be achieved. This high thermal recovery represents a significant improvement over cyclic efficiencies of existing residential heating systems which are normally at about 75 to 80 percent (references 3-4, 3-5).

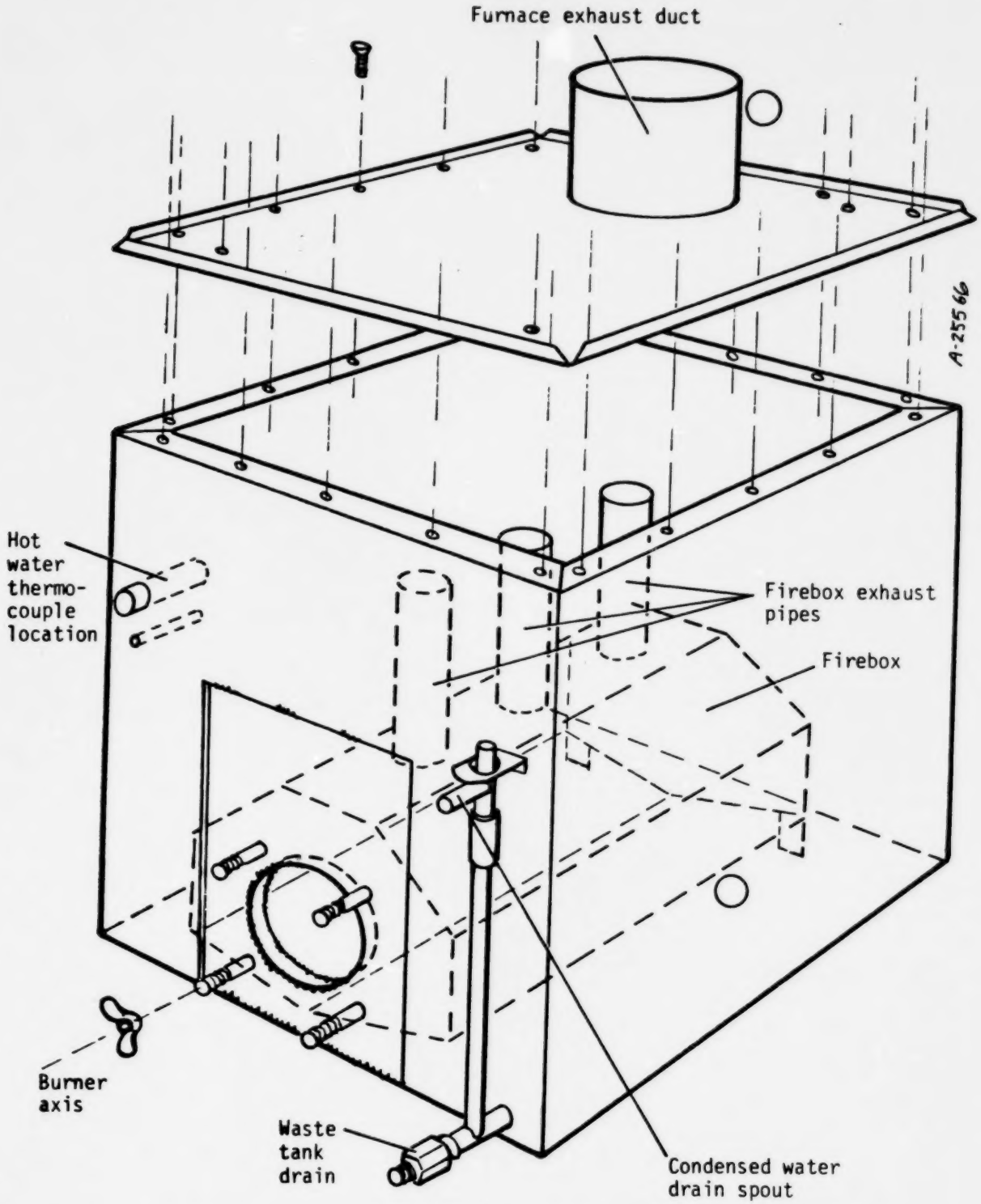

Figure 3-3. Schematic of the Hot Water Tank (reference 3-3)

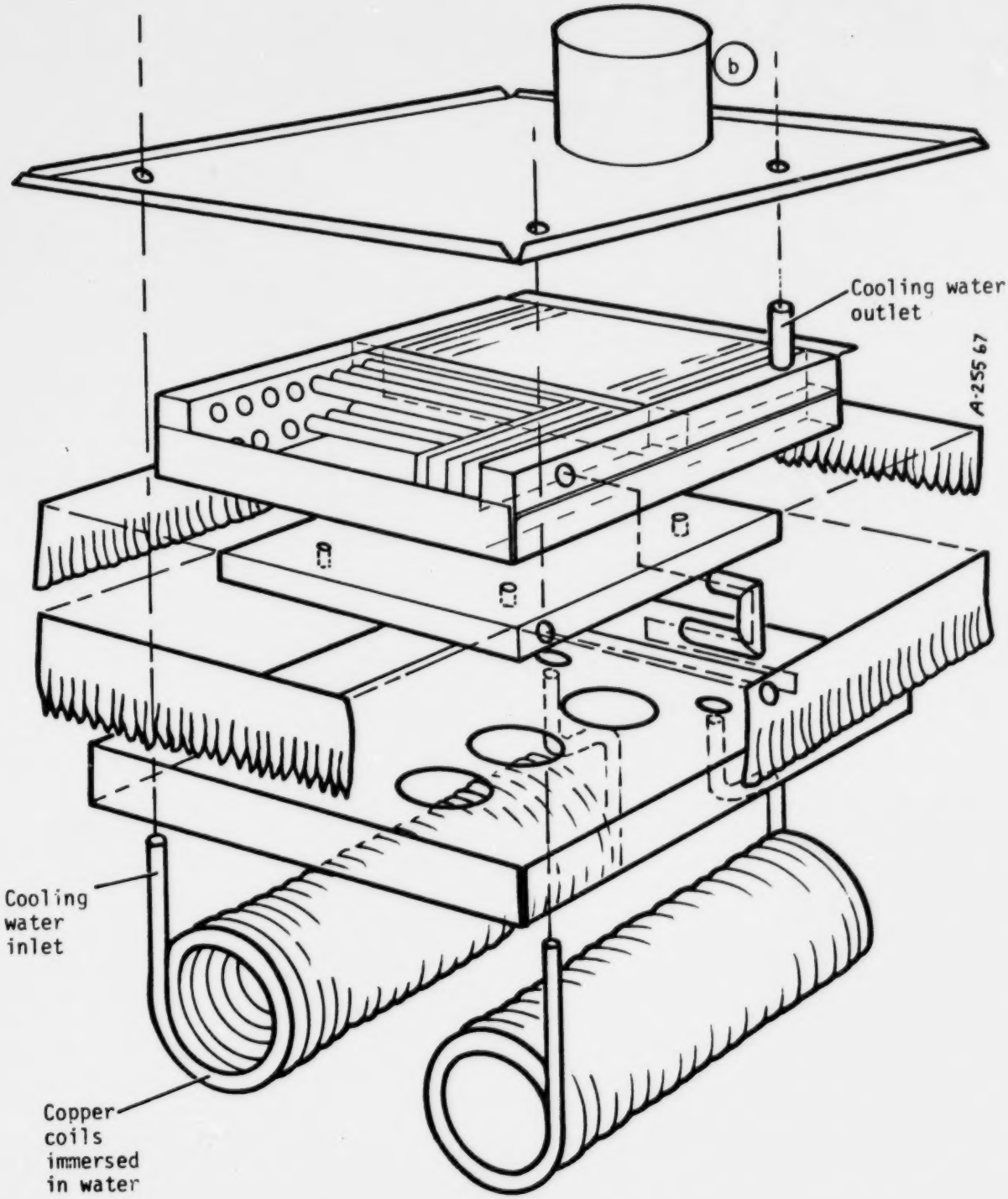

Figure 3-4. Heat Exchanger Assembly (reference 3-3)

REFERENCES FOR SECTION 3

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3-2. "The Blueray System," Fuel Oil & Oil Heat, Vol. 36, No. 5, pp. 42-44, May 1977.

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SECTION 4

EMISSIONS RESULTS

The objectives of this test program were to measure exhaust emissions during normal cyclic operation and to quantify the pollutant concentrations in the water stream leaving the furnace. This section describes the test arrangement and presents emissions results measured in the exhaust flow gas duct and condensed water leaving the tank.

4.1 FURNACE OPERATION AND TEST ARRANGEMENT

The condensing hot water residential furnace tested in this program has just recently been introduced to the North American market. Although in widespread use in some countries in Western Europe, there are no known domestic installations in the United States or Canada. Therefore, a new unit was obtained by the Danish Aircraft Systems A/S in cooperation with the Karlsons Blueburner Systems Ltd. of Canada. This unit was set up in the Acurex combustion laboratory where access to emissions monitoring equipment was relatively straightforward.

Since the test program called for analysis of water samples collected during and at the conclusion of the test, the interior surfaces of the water tank, exhaust duct, and cooling coils were subjected to rigorous cleaning prior to the test. The objective of the cleaning procedure, which included water with soap wash followed by distilled water rinse, methyl alcohol, and methylene chloride in that order, was to remove

all traces of solid organic and inorganic material which might contaminate the initial water charge and lead to erroneous test conclusions.

Following the cleaning procedure, the tank and coils were rinsed with an initial charge of tap water poured into the tank through the exhaust flue gas duct. The tank and heat exchanger coils were rinsed by first filling the tank to its capacity, approximately 56.8 l (15 gal), then draining the water through the drain plug. After the tap water rinse, approximately 41.6 l (11 gal) were poured into the tank. This water served as the initial charge used for the test program. A tap water sample and a sample obtained from the water in the tank were collected to establish the initial contaminants in the water by laboratory analysis at the start of the test.

In order to obtain water samples representative of "as-found" furnace conditions, it was necessary to condition the initial charge of tap water in the tank by operating the furnace over a period of a few days under normal domestic operating practices. Thus the furnace was left operating in a cyclic mode (approximately 10 min on, 20 min off) for about one week. The condensed flue gas water raised the level of the tank water to the overflow setting. Any water collected from the overflow drain was then monitored intermittently for its pH level. After the week of preconditioning the water, the pH level reached a constant value of about 3.0. At that point, another water sample was taken from the tank drain valve to be analyzed for anions, trace elements, and condensed organic concentrations. This sample, together with the water sample collected at the end of the test, served to establish the steady state reached through the conditioning period of the tank water. An electronic data logger

(Autodata 8) was used to record temperatures of ambient air, stack flue gas, inlet water, outlet water, and tank water on a 1-min interval during both burner-on and burner-off periods.

Table 4-1 summarizes burner and furnace operating settings throughout the test program. Cycle frequency of the burner was controlled by adjusting the setting of the tank water thermostat and the cooling water flow rate. A thermostat setting of approximately 54°C (129°F) and a cooling water flow rate of 107 ml/s (1.7 gal/min) resulted in burner cycle frequencies of 11 to 14 min on, 22 to 25 min off. These settings were maintained nearly constant throughout the test period. Figure 4-1 illustrates the temperature profiles measured with the data logger during a typical on-off burner cycle.

The following section presents emissions measured in both gaseous and liquid streams leaving the furnace.

4.2 FLUE GAS AND WATER EMISSIONS

The sampling and analysis procedures used in this test program conform to the EPA Level 1 protocol (reference 4-1) for gas and liquid streams. Flue gas measurements were made at the exit of the furnace at approximately 1m (3 ft) from the base of the uninsulated exhaust pipe, as shown in figure 4-2. Flue gas measurements included:

- Continuous monitors for NO, NO_x, CO, CO_2, O_2, TUHC
- Source Assessment Sampling System (SASS) for trace elements and organic emissions
- EPA Method 5 for solid and condensable particulate mass emissions
- EPA Method 8 for sulfur species (SO_2, SO_3)

Table 4-1. Hot Water Residential Heating System Test Operating Conditions

• M.A.N. burner operating condition:	
-- Burner oil pressure	1.03 MPa (150 psig)
-- Oil temperature	ambient
-- Burner on-time	11 to 14 min
-- Burner off-time	22 to 25 min
-- Distillate oil flow	0.45 ml/s (0.49 gal/hr)
• Hot water heating system initial settings and operating conditions:	
-- Tank water capacity	~56.8 l (15 gal)
-- Tank water at start of test	~53.0 l (14 gal)
-- Cooling water flow	107 ml/s (1.7 gal/min)
-- Tank water thermostat setting	54 to 55°C (129 to 131°F)
-- Average inlet water temperature	13°C (56°F)
-- Average rise of outlet water temperature	19°C (35°F)
-- Average rise of tank water temperature	32°C (58°F)
-- pH of tank water	2.7
-- Approximate tank water discharge rate	~0.47 ml/s (0.43 gal/hr)
-- Flue gas temperature	16.7 to 27.8°C (62 to 82°F)

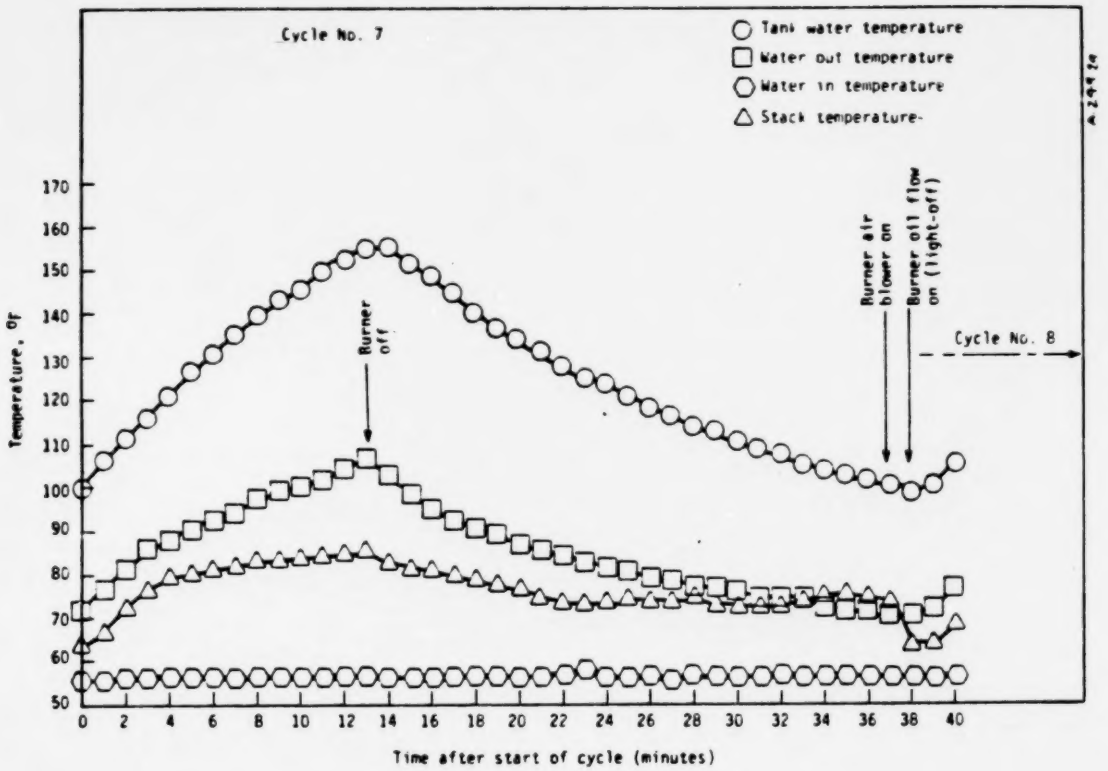


Figure 4-1. Hot Water Residential Heater Temperature Profiles

- Grab sample for onsite analysis of C_1 - C_6 hydrocarbons by gas chromatography
- Bacharach smoke spot

Appendix A describes this equipment, and the sampling and analytical procedure used.

4.2.1 Criteria Pollutant and Other Vapor Phase Emission Results

Table 4-2 lists emissions of CO, CO_2, NO, NO_2, TUHC, particulate, sulfur oxide, and smoke in the flue gas during the period of firing. During the test there were peaks of CO and hydrocarbon emissions at the start and end of burner-on times. The peak emissions at the start of each cycle are included in the reported levels; however, the effects of burner shut-off were not evaluated. Since the blower and the fuel pump were shut off at the same time, there was no forced air when the burner was shut off. Thus, the combustion air flowrate is unknown, and the CO and hydrocarbon emission rates at the end of the firing cycle cannot be evaluated.

Burner startup peak emissions averaged 150 ppm for CO and 15 ppm for hydrocarbons. The NO started at zero and reached approximately 70 ppm on the average, at 1.9 percent average O_2. Smoke emissions measured with the Bacharach hand pump kit were zero during the entire burner-on period. Figure 4-3 is a copy of a portion of the strip chart recorder depicting emission traces for CO, CO_2, NO, and O_2 during one typical burner on-off cycle operation of the furnace.

NO emissions averaged 37.1 ng/J, as NO_2, over the duration of the test. This level, although significantly higher than NO emissions measured for a Blueray warm air furnace (reference 4-2), represents a 40 percent

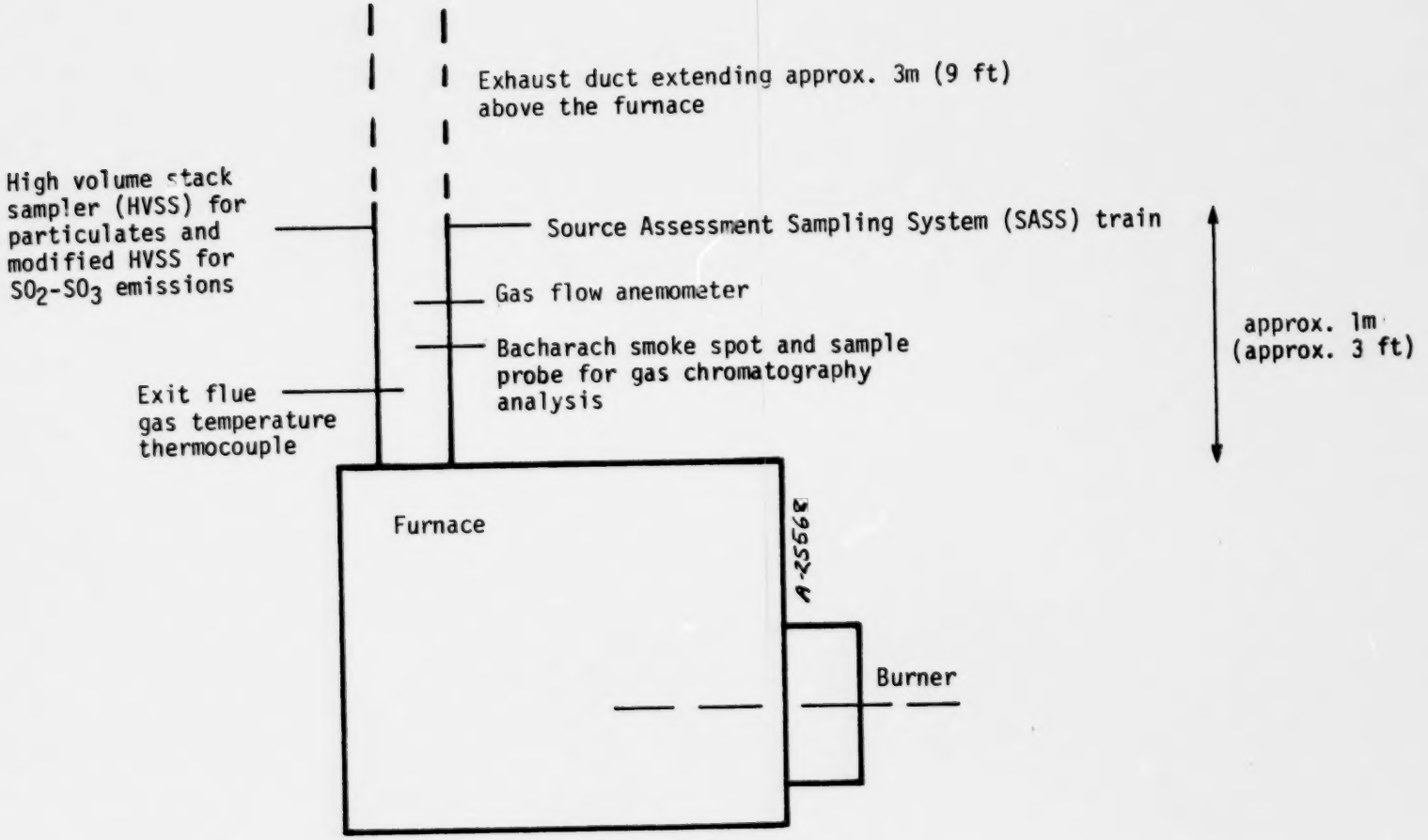


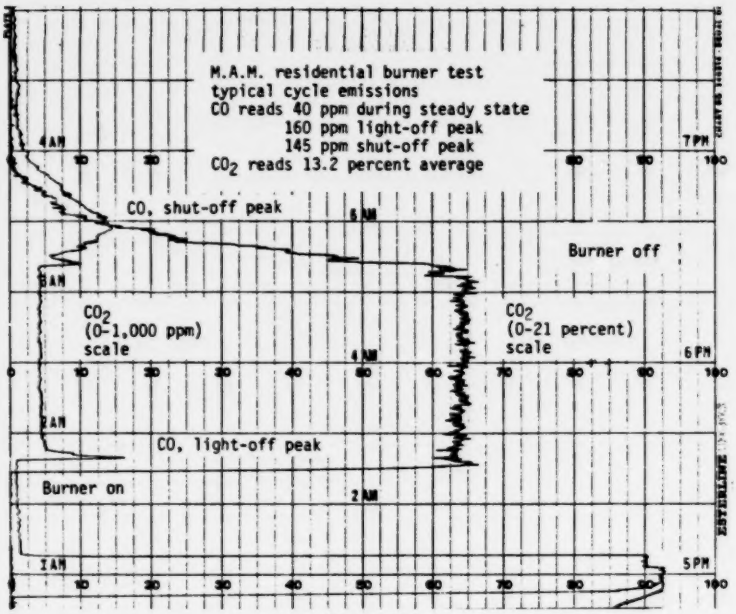
Figure 4-2. Gas Sampling Locations

Table 4-2. Flue Gas Emissions[a]

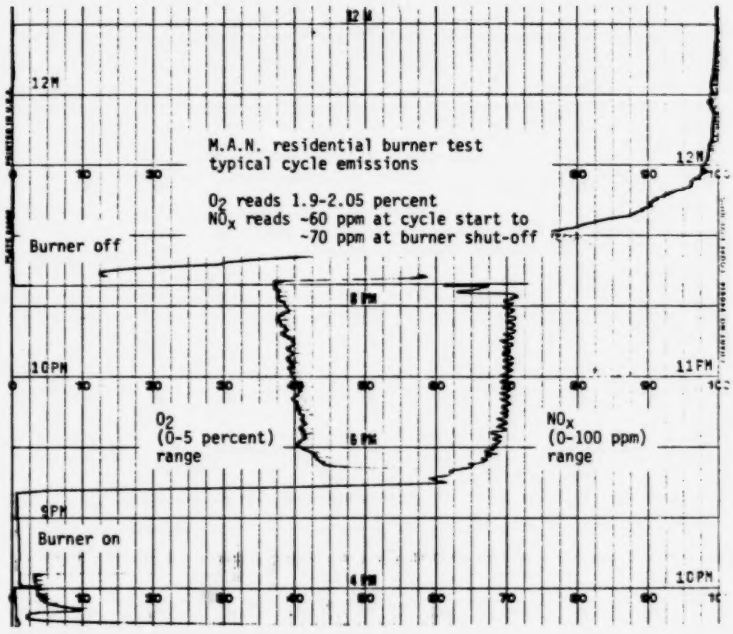
Species	Range	Average
O_2 (percent dry)	1.4 - 2.4	1.9
CO_2 (percent dry)	12.6 - 14.0	12.9
H_2O (percent)	2.7 - 3.0	2.9
CO[a] (ppm @ 0 percent O_2)	15 - 51	40
(ng/J)	4.5 - 15.2	11.9
NO (ppm @ 0 percent O_2)	68 - 79	76
(ng/J as NO_2)	33.2 - 38.6	37.1
NO_2	0[b]	0
TUHC (ppm @ 0 percent O_2)	0.5 - 9	3.3
(ng/J as C_3H_8)	0.2 - 4.1	1.5
SO_2 (ppm @ 0 percent O_2)	--	156
(ng/J)	--	106.3
SO_3	0[b]	0
Solid particulate (ng/J) Method 5	--	1.3
Condensable particulate (ng/J) Method 5	--	1.4
Solid particulate (ng/J) SASS	--	1.2
Smoke (Bacharach)	0	0

[a]Includes peak emissions at the start of burner-on cycle

[b]NO_2 and SO_3 were absorbed in the condensing water



CO and CO_2



O_2 and NO_x

Figure 4-3. Strip Chart Recordings of Emissions During a Typical Burner Cycle

emissions reduction from conventional residential heating systems burning distillate oil (reference 4-3). The effect of condensation of flue gas moisture on NO_2 emissions was obvious in that apparently any NO_2 present in the flue gas was absorbed by the condensed moisture and eventually ended up in the tank water. Analysis of anions in the tank water and condensate drain collected during the test shows, in fact, that nitrates were present in the water. Results of water analysis are presented in section 4.2.2.

It should be noted that the level of NO measured during this test program may not be fully representative because of the relationship between fuel nitrogen and NO emissions. Table 4-3 summarizes the ultimate analysis of the distillate oil used in the program. As indicated, the nitrogen content of the oil averaged 0.04 percent making it a relatively high nitrogen distillate. Assuming 100 percent conversion of fuel nitrogen to NO, its contribution to total NO emissions could account for nearly 80 percent. Thus, for lower nitrogen distillate oils, NO emissions from this furnace may be lower than the 37.1 ng/J (as NO_2) measured during the current tests.

Sulfur species (SO_2 and SO_3) in the exhaust gas were analyzed by EPA Method 8, and sulfate on particulate by turbimetric methods. As expected, SO_2 was the only sulfur species found in the exhaust gas. Both gaseous SO_3 and sulfate were apparently absorbed in the condensing water; sulfur leaving the furnace as SO_2 accounted for 118 percent of the total fuel sulfur input based on a fuel oil analysis of 0.2 percent sulfur and 44.6 MJ/kg (19,190 Btu/lb) heating value.

Particulate emissions were measured by both EPA Method 5 and SASS techniques. Solid particulate matter collected on the filter and inside

Table 4-3. Ultimate Fuel Analysis of Distillate Oil (Percent by Weight)

Carbon (C)	86.94
Hydrogen (H)	13.23
Sulfur (S)	0.20
Nitrogen (N)	0.04
Oxygen (O) (by difference)	--
Heating value	44.6 MJ/kg (19,190 Btu/lb)
Gravity ^{o}API @ 60^{o}F	33.75

the probe were very consistent between the two sampling techniques: 1.3 versus 1.4 ng/J. Particulate matter condensed in the impinger section of the Method 5 train accounted for about 50 percent of the total particulate matter emissions.

Bacharach smoke emissions were measured throughout the test program at various time intervals after fuel light-off. Smoke numbers were consistently zero throughout each firing period. The absence of smoke and relatively low CO emission peaks during burner light-off are attributable to the fuel oil delay valve of the M.A.N. burner which prevented ignition for approximately 15 sec after the burner blower went on.

4.2.2 Trace Element Analyses

The fuel sample from the inlet to the furnace, the SASS train samples from the furnace gas outlet, and water discharge samples were analyzed for 73 trace elements using Spark Source Mass Spectrometry (SSMS) and Atomic Absorption (AA) techniques. Once the trace element concentrations were determined by laboratory analysis, trace element flowrates for fuel inlet, flue gas vapor and condensed phases, and water discharges could be computed. Trace element concentrations and flowrates are presented in appendix B.

Distillate fuel oil is relatively free of mineral matter, thus inorganic emissions from combustion of this fuel are generally very small. Table 4-4 summarizes trace element levels above the detection limit of the analysis in the fuel oil, exhaust gas and water discharge samples. As shown, the concentration of most of the elements in all input and output streams is well below the ng/J level. Of all trace elements in the fuel oil, chlorine, aluminum, calcium, potassium, titanium, silicon, and iron were found at the highest concentrations (0.112 to >2.24 ng/J).

Table 4-4. Trace Element Emissions (pg/J)

Element	Fuel Oil	Flue Gas	Water	Closure Out/In
Aluminum	>2200	>27	11	>0.017
Antimony	--[b]	0.019	0.44	--
Arsenic	0.45	0.065	0.20	<0.59
Barium	6.7	1.5	--	0.22
Boron	0.90	>21	0.66	>24
Bromine	67	0.66	--	0.0098
Cadmium	0.45	--	0.13	0.29
Calcium	>2200	>21	--	>0.0092
Cereium	--	0.058	--	--
Cesium	--	0.016	--	--
Chlorine	1600	--	--	--
Chromium	9.0	1.3	11	1.4
Cobalt	0.90	0.42	1.5	1.8
Copper	11	2.2	11000[a]	1000
Fluorine	22	5.3	2.2	0.33
Gallium	0.45	0.034	--	0.076
Iron	220	5.9	150	0.71
Lanthanum	--	0.42	--	--
Lead	4.5	1.1	1.3	0.53
Lithium	0.45	0.090	--	0.20
Magnesium	45	14	33	1.1
Manganese	4.5	0.52	2.2	0.61
Mercury	<2.2	0.18	--	<0.082
Molybdenum	<2.2	1.1	2.2	1.5
Neodymium	--	0.0021	--	--
Nickel	22	3.3	15	0.83
Phosphorus	22	0.85	8.8	0.43
Potassium	160	16	22	0.24

— Continued —

Table 4-4. Concluded

Element	Fuel Oil	Flue Gas	Water	Closure Out/In
Rubidium	0.22	0.016	--	<0.071
Scandium	<0.22	--	0.2	<0.99
Selenium	--	0.096	2.2	--
Silicon	560	>30	88	>0.21
Silver	--	0.0021	--	--
Sodium	90	>85	--	>0.94
Strontium	--	0.085	--	--
Sulfur	4.5	18	>220	>53
Tantalum	--	0.19	0.88	--
Tellurium	4.5	0.16	0.13	0.065
Tin	0.67	0.042	<0.13	<0.26
Titanium	110	5.0	2.2	0.064
Vanadium	0.45	0.42	--	0.94
Yttrium	0.45	0.11	<4.4	<10
Zinc	16	2.9	>220	>14
Zirconium	0.90	--	0.22	0.25

[a]SSMS analysis resulted in a less accurate value of about >0.22 ng/J instead of value obtained with AA analysis shown here; leaching of copper coils is suspected.

[b]Dashes indicate levels below the detection limit.

No traces of chlorine were found in the flue gas suggesting that it also was absorbed into the tank water. For the other elements only a fraction of the fuel oil concentration was accounted for by the flue gas and the tank water discharge.

Copper, molybdenum, zinc, cobalt, chromium, and boron show outlet concentrations higher than accounted for by the fuel oil. With the exception of boron, the contribution of these elements in the tank water was significantly higher than that from the flue gas. This is true especially for copper which had the highest concentration of any element in the waste water. This copper concentration suggests that leaching of heat transfer copper coils may have occurred. Leaching of other metal surfaces may have contributed to high concentration of other metallic elements. Nickel, however, also an element found in the stainless steel tank, did not show an outlet concentration higher than that in the fuel oil. Cobalt and boron results are questionable.

The sulfur content of the fuel oil by SSMS is significantly lower than sulfur content measured by the ultimate fuel analysis. This is due to oxidation of the sulfur to SO_2 during pretreatment of the fuel oil sample prior to SSMS analysis.

Measurement of the anions in the tank water discharge shows the presence of chloride, nitrate, and sulfate. Chloride is most likely due to conversion of chlorine in the fuel to hydrochloric acid (HCl) and subsequent HCl absorption in the condensing water. Nitrate and sulfate anions are due to the absorption of NO_2 and SO_3, respectively, by condensed flue gas water vapor, which drops into the tank water and is then discharged by the furnace.

4.2.3 Organic Analyses

Organic analyses were performed on selected flue gas samples according to the EPA Level 1 protocol outlined in appendix B (reference 4-1). Gaseous C_1 to C_6 hydrocarbon compounds in the flue gas having boiling points nominally less than 100°C (212°F) were analyzed onsite by gas chromatography. Samples collected in the SASS train were extracted with methylene chloride in a Soxhlet apparatus. The extracts were then subjected to Total Chromatographable Organic (TCO) and gravimetric (GRAV) analyses which determine species with boiling points nominally in the ranges of 100 to 300°C (212 to 572°F) and greater than 300°C (572°F). Infrared (IR) spectra of the total sample extracts were also performed. Liquid column chromatography (LC) separations of the organic sorbent extract was performed followed by IR analyses of organics eluted in each LC fraction and Low Resolution Mass Spectrometry (LRMS) of those fractions containing organic matter in excess of 0.5 mg/dscm. In addition, Gas Chromatography/Mass Spectrometry (GC/MS) analysis of total sample extracts was performed to identify specific polynuclear aromatic and other organic compounds. A discussion of the analytical results follows.

4.2.3.1 C_1 to C_6 Flue Gas Hydrocarbon Analysis

Onsite analysis of C_1 to C_6 flue gas hydrocarbons was conducted during the test. The grab samples were taken at different times during the duration of a cycle: at startup of the burner, 5 min into the cycle, and at the end of the cycle. The results of these analyses are presented in table 4-5. As shown, the concentrations of C_1 to C_6 hydrocarbon emissions were less than the ppm level.

Table 4-5. C_1 to C_6 Flue Gas Hydrocarbon Analysis (ppm, dry)

Test Time	Beginning of Burn Cycle	5 Min into Burn Cycle	End of Burn Cycle
C_1 (methane)	0.4	<0.2	<0.2
C_2 (ethane)	<0.2	<0.2	<0.2
C_3 (propane)	<0.5	<0.5	<0.5
C_4 (butane)	<0.5	<0.5	<0.5
C_5 (pentane)	<1.0	<1.0	<1.0
C_6 (hexane)	<1.0	<1.0	<1.0

These results contrast with the total hydrocarbon emission data measured with continuous Flame Ionization Detector (FID) data. The FID data reported in section 4.2.1 indicated levels ranging from 0 to 9 ppm and an average of 3.3 ppm. In light of the Gas Chromatography (GC) analyses reported here, the continuous FID analyzers are not sensitive to hydrocarbon levels in the range of 1 to 5 ppm.

4.2.3.2 Total Chromatographable Organic (TCO) and Gravimetric Analyses of Organic Extracts

TCO and gravimetric analyses were performed on the filter, XAD-2 sorbent, and organic module condensate extracts. The results of the analyses for both flue gas and waste water samples are presented in table 4-6. The flue gas results indicate that 74 percent of all the organic emissions were of compounds in the TCO range and collected in the XAD-2. The total concentration of organic matter in the flue gas measured only 3.5 mg/dscm. This organic emission concentration compares to an average of 5.0 mg/dscm measured from five conventional residential warm air furnaces (reference 4-4) and 26.3 mg/dscm for one low-NO_x furnace design (reference 4-2), all burning distillate oil and operating in a cyclic mode. The water analysis results indicate that some organic matter condensed in the water; however, the total concentration measured less than 0.1 mg/l of waste water discharge, corresponding to an emission rate significantly lower than that of the flue gas stream.

4.2.3.3 Infrared (IR) Spectra of Total Extracts

The results of the IR spectra determinations for the total extract samples are summarized in table 4-7. IR spectrometry is used to identify the organic functional groups present in the sample. The spectra suggested the potential presence of aliphatic hydrocarbons and alcohols in all samples. The XAD-2 extract and the tank discharge contain many more organic categories.

Table 4-6. Results of TCO and Gravimetric Analyses of Total Extract Samples

Stream	Sample	TCO Results (mg)	Gravimetric Results (mg)	Total Organic in the Sample (mg)	Concentration in the Sample (mg/dscm)
Flue gas	Filter	--	3	3	0.1
	XAD-2 extract	74	18	92	3.2
	Organic module condensate extract	<0.02	5	5	0.2
	Total flue gas sample	74	26	100	3.5
Water	Tap water	<0.02	<2	<2	(mg/l) <0.1
	Tank water blank	<0.02	<2	<2	<0.1
	Tank water discharge	0.5	<2	0.5	<0.1

Table 4-7. Summary of Infrared Spectrometry Analysis of Total Extract Samples

Stream	Sample Type	Compound Categories Potentially Present
Flue gas	XAD-2 extract	Aliphatic hydrocarbons, carboxylic acids, esters, alcohols, ketones, aldehydes, amines
	Organic module condensate extract	No peaks
	Filter	No peaks
Water	Tap water	No peaks
	Tank water blank	No peaks
	Tank water discharge	Aliphatic hydrocarbons, sulfonamide

4.2.3.4 Liquid Chromatography Fractionation

The XAD-2 sample extract was separated via liquid chromatography to fractionate the organic matter into seven polarity fractions. Results of TCO and GRAV analyses of each fraction are summarized in table 4-8.

Table 4-8. Gravimetric and TCO Results of Column Chromatography of the XAD-2 Sample[a]

Fraction	TCO (mg)	Gravimetric (mg)	Total	
			(mg)	(mg/dscm)
LC1	52	23	75	2.6
LC2	0.2	2	2	0.07
LC3	0.85	<2	<3	0.1
LC4	0.1	<2	<2	<0.07
LC5	<0.01	<2	<2	<0.07
LC6	<0.01	2	2	0.07
LC7	<0.01	4	4	0.14
Total	53	31	84	3.0

[a]Results are based on total organics recovered in each fraction corrected to total organics in the original sample.

Results indicate that 90 percent of the organic matter eluted in the first fraction, which typically contains aliphatic hydrocarbons. Lesser amounts eluted in fractions 2, 3, 6, and 7, which generally contain aromatics (LC2 and LC3) and oxygenates (carboxylic acids, alcohols, esters, ketones, etc. -- LC6 and LC7).

4.2.3.5 Infrared and Low Resolution Mass Spectral (IR and LRMS) Analyses of Fractions from Column Chromatography

Samples from column chromatography fractionation of the organic sorbent extract were analyzed using Level 1 infrared and Low Resolution Mass Spectral

(LRMS) techniques. Table 4-9 summarizes the IR results. Only LC1 and LC3 (which contained most of the organic matter) show interpretable spectra.

Table 4-9. Infrared Analysis of Column Chromatography Fractions

Fraction	Frequency, cm^{-1}	Intensity[a]	Possible Assignment
LC1	2920--2840	S	CH aliphatic
LC2	--	--	No peaks
LC3	3500--2940	S	OH alcohols
LC4	2920--2840	S	CH aliphatic
LC5	--	--	No peaks
LC6	--	--	No peaks
LC7	--	--	No peaks

[a]S = strong intensity

LRMS analysis was performed only on LC1 because this fraction alone exceeded the 0.5 mg/dscm threshold established in the Level 1 protocol. Results of this analysis confirmed the presence of aliphatic hydrocarbons as the major organic category present.

Table 4-10 summarizes organic analysis results for the exhaust gas stream from the residential heater. The top portion of the table summarizes the Total Chromatographable Organic (TCO) and Gravimetric (GRAV) analyses of the organic sorbent XAD-2 extract eluted in the seven liquid chromatography fractions (LC). The bottom portion of the table summarizes the organic categories found in each sample using infrared spectrometry (IR) and Low Resolution Mass Spectrometry (LRMS) and their estimated concentrations based on the total organic level in the sample. In summary, aliphatic

Table 4-10. Organic Extract Summary -- XAD-2 Sorbent Extract

	LC1	LC2	LC3	LC4	LC5	LC6	LC7	$\sum$
Total Organics, mg	75	2	<3	<2	<2	2	4	85
TCO, mg	52	0.2	<0.85	<0.1	<0.02	<0.02	<0.02	54
GRAV, mg	23	2	<2	<2	<2	2	4	31

Category	Assigned Intensity -- mg/dscm							
	LC1	LC2	LC3	LC4	LC5	LC6	LC7	
Aliphatic HCs	100--2.6							2.6
Aldehydes			100-<0.11					0.11
Carboxylic Acids							100--0.14	0.14

hydrocarbons account for nearly 90 percent of all the organic matter while alcohols and carboxylic acids, esters, ketones, or amines account for the remaining 10 percent.

4.2.3.6 Gas Chromatography/Mass Spectrometry Analysis of POM Compounds

Gas Chromatography/Mass Spectrometry (GC/MS) analyses of gas sample extracts were performed to detect and quantify specific polycyclic organic matter and other organic compounds. The compounds sought in the analysis and their respective detection limits are listed in table 4-11. The results of the GC/MS analyses are summarized in table 4-12. As shown, naphthalene and phenanthrene were the only POM's found to be in concentrations above the detection limit of the analysis. The concentrations of these compounds in the exhaust gas are two orders of magnitude lower than the total organic concentration of 3.5 mg/dscm.

4.2.3.7 Summary of Organic Emissions

Most of the organic compounds detected in the exhaust gas of the Hadwick/Karlsons furnace are aliphatic hydrocarbons (about 90 percent). These hydrocarbons are probably directly attributable to unburned fuel oil in the flue gas which is often the result of frequent burner startups. Small amounts of oxygenated compounds (carboxylic acids, alcohols, ketones, esters, etc.) were also apparently present. They can be attributed to partially burned fuel. Some POM compounds in low concentrations were found, but these make up a small portion of the total hydrocarbon emissions; their concentrations are significantly below hazardous guideline levels used by EPA to establish the need for further testing. A discussion of these hazardous guideline levels in given in section 5.

Table 4-11. Compounds Sought in GC/MS Analysis and Their Detection Limits (ng)

8[a]	4-bromophenyl phenyl ether	40[a]	indeno(1,2,3-cd)pyrene
1[a]	bis(2-chloroisopropyl)ether	2[a]	pyrene
2[a]	bis(2-chloroethoxy)methane	20	2,3,7,8-tetrachlorodibenzo-p-dioxin
8[a]	hexachlorobutadiene	2[a]	acenaphthene
40[a]	hexachlorocyclopentadiene	100[a]	benzidine
1[a]	isophorone	8[a]	1,2,4-trichlorobenzene
1[a]	naphthalene	8[a]	hexachlorobenzene
8[a]	nitrobenzene	8[a]	hexachloroethane
4[a]	N-nitrosodiphenylamine	3[a]	bis(2-chloroethyl)ether
40[a]	N-nitrosodi-n-propylamine	2[a]	2-chloronaphthalene
3[a]	bis(2-ethylhexyl)phthalate	4[a]	1,2-dichlorobenzene
3[a]	butyl benzyl phthalate	8[a]	1,3-dichlorobenzene
1[a]	di-n-butyl phthalate	4[a]	1,4-dichlorobenzene
2[a]	di-n-octyl phthalate	20[a]	3,3-dichlorobenzidine
2[a]	diethyl phthalate	10[a]	2,4-dinitrotoluene
2[a]	dimethyl phthalate	10[a]	2,6-dinitrotoluene
5[a]	benzo(a)anthracene	1[a]	1,2-diphenylhydrazine (as azobenzene)
7[a]	benzo(a)pyrene	2[a]	fluoranthene
8[a]	3,4-benzofluoranthene	4[a]	4-chlorophenyl phenyl ether
8[a]	benzo(k)fluoranthene	40	anthanthrene
5[a]	chrysene	40	benzo(e)pyrene
1[a]	acenaphthylene	--[b]	dibenzo(a,H)pyrene
1[a]	anthracene	--[b]	dibenzo(a,i)pyrene
40[a]	benzo(ghi)perylene	40	dibenzo(c,g)carbozole
2[a]	fluorene	40	7,12 dimethyl benz(a)anthracene
1[a]	phenanthrene	40	3-methyl cholanthrene
40[a]	dibenzo(a,h)anthracene	40	perylene
		40	benzo(c)phenanthrene

[a]Authentic standard run
[b]Molecular weight too high for direct analysis by base/neutral run

Table 4-12. Results of Quantification of POM Compounds

Compound	Molecular Weight	Quantity (ng)				Total Emissions	
		Filter	XAD-2	OMC	Tank Water	Flue gas (µg/dscm)	Water (µg/l)
Naphthalene	128	<1	94	<1	9	36	0.4
Phenanthrene/ anthracene	178	<1	4	<1	2	2	0.08

REFERENCES FOR SECTION 4

4-1. Lentzen, D. E. et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment," EPA-600-2-76-160a, NTIS PB 275 850/AS, June 1976.

4-2. Higginbotham, E. B., "Combustion Modification Controls for Residential and Commercial Heating Systems: Volume II, Oil-Fired Residential Furnace Test," EPA-600/7-81-123b, July 1981

4-3. Castaldini, C., "Combustion Modification Controls for Residential and Commercial Heating Systems: Volume I Environmental Assessment," EPA-600/7-81-123a, July 1981.

4-4. Surprenant, N. F. et al., "Emission Assessment of Conventional Stationary Combustion Systems, Volume 1: Gas- and Oil-Fired Residential Heating Sources," EPA-600/7-79-029b, May 1979.

SECTION 5

ENVIRONMENTAL ASSESSMENT

This section presents the potential environmental impact for the source tested and discusses the bioassay testing of flue gas and water discharge samples collected from the furnace. The environmental impact is quantified using a Source Analysis Model (SAM) developed for general use within all IERL EA programs. Bioassay analyses are conducted for testing the toxicity and mutagenicity of waste streams. Both the SAM and bioassay analyses are aimed at identifying problem areas and providing the basis for ranking streams for further consideration in the environmental assessment.

5.1 SOURCE ANALYSIS MODEL EVALUATIONS

The model used to evaluate the Level 1 data obtained from the M.A.N./ Hadwick residential furnace system is the rapid screening model, SAM IA (reference 5-1). SAM IA includes no treatment of pollutant transport or transformation, so evaluations employ effluent stream concentration goals, termed Discharge Multimedia Environmental Goals (DMEG's, reference 5-2, 5-3) A compound's DMEG corresponds to a concentration considered safe for acute exposure.

The SAM IA model defines two indices of potential hazard. The first, termed Discharge Severity (DS), is defined as the ratio of the concentration of a pollutant to its DMEG. In Level 1 evaluations, the

discharge concentration used is that determined for each MEG category of components analyzed in the effluent sample, while the DMEG used is that for the most toxic species potentially present for the MEG category. A stream Total Discharge Severity (TDS) is also defined as the sum of the DS's calculated for the discharge stream. When a DS exceeds unity, more refined chemical analysis may be required to quantify specific compounds present.

The second SAM IA hazard index, termed Weighted Discharge Severity (WDS), is defined as the product of DS with the discharge stream mass flowrate. The WDS is an indicator of the magnitude of a potential hazard and can be used to rank the needs for controls for waste streams.

SAM IA evaluations were performed on each set of test data reported in section 4 using health-based DMEG's. Results are summarized in table 5-1. Only discharge severities for those species with a DS greater than 0.1 are listed.

In the flue gas stream, NO and SO_2 emissions were responsible for the highest DS values, both exceeding unity by nearly a factor of 10. The DS for CO and total hydrocarbons (primarily aliphatic) suggest that these were present in nonhazardous concentrations (DS <1.0). Four elements with DS greater than 0.1 were found in the flue gas. These were chromium, nickel, sodium, and sulfur, with only chromium having a DS exceeding unity. Both chromium and nickel emissions, however, are suspected contaminants in sample preparation prior to the Spark Source Mass Spectrometry (SSMS) analysis.

The only organic categories of potential concern in the flue gas emissions are aldehydes, with DS of 0.4 and carboxylic acids, with DS of 0.2. These DS values were calculated assuming that the organic matter eluting in LC3 (for aldehydes) and in LC6 and LC7 (for carboxylic acids) of the XAD-2

Table 5-1. Flue Gas and Water Discharge Severities (Health-Based) Greater than 0.1 for the Hadwick Furnace Equipped with Low-NO_x M.A.N. Burner

Pollutant	MEG Category	Flue Gas	Tank Water Discharge
Copper, Cu	78	3.0×10^{-2}	100
Sulfate, $SO_4^=$	53	--	67
NO	47	11.0	--
SO_2	53	10.0	--
Iron, Fe	72	1.5×10^{-2}	6.7
Nickel, Ni	76	0.57	4.4
Chromium, Cr	68	3.4	2.8
Selenium, Se	54	1.3×10^{-3}	2.0
CO	42	0.77	--
Manganese, Mn	71	2.8×10^{-4}	0.76
Sulfur, S	53	0.48	--
Zinc, Zn	81	1.9×10^{-3}	>0.4
Aldehydes	7A	0.40	--
Lead, Pb	46	1.9×10^{-2}	0.28
Carboxylic acids	8A,B	0.20	--
Sodium, Na	28	>0.11	--
Total Discharge Severity (TDS)[a]	--	27.0	185
Weighted Discharge Severity (WDS)[b], g/s	--	2,600	8.7

[a] $TDS = \Sigma_i \, DS_i$

[b] $WDS = \dot{M} \times \Sigma_i \, DS_i$, where $\dot{M}$ is the mass flowrate of the stream in grams per second.

extract consisted entirely of the compound with the lowest DMEG in the respective organic categories potentially present. Table 4-10 noted that aldehydes were possibly present in LC3. The DS for this category was calculated assuming the LC3 organic content consisted entirely of acrolein, the aldehyde with the lowest DMEG. Correspondingly, table 4-10 noted that carboxylic acids, alcohols, esters, ketones, or amines were potentially present in LC6 and LC7 fractions. In addition, IR data suggest that none of these are aromatic. Thus the compound with the lowest DMEG consistent with the above is a carboxylic acid (saturated long chain acids of molecular weight between 228 and 285). The DS noted in table 5-1 assumes the entire amount of LC6 and LC7 organics in the XAD-2 extract consisted of this compound. Thus, these DS values represent conservative estimates of the potential hazard posed by organic emissions from the furnace.

Trace elements in the tank water for which DS exceeded unity were found to be copper, chromium, iron, nickel, and selenium. Copper levels significantly exceeded those of any other trace element in the waste water. The high concentration of copper in the waste water is attributed to leaching of heat transfer copper coils immersed in the warm acidic water. In fact, concentrations of most other metallic trace elements including iron, chromium, lead, nickel and zinc can also be attributed to leaching of metal surfaces in contact with the water. Sulfates, nitrates and chloride concentrations of about 1,000, 7 and 3 mg/l resulted in DS values of 67, 0.093, and 0.17, respectively. Sulfuric acid in the waste water represents the greatest potential environmental concern, second only to copper.

Total discharge severity for the liquid stream exceeded that of the gas stream due primarily to the high concentrations of copper and sulfates.

Table 5-2. Bioassay Analysis Results

Sample	Evaluation[a]		
	CHO[b]	Ames[c]	RAT[b]
Organic sorbent XAD-2	L/ND	M[c]	--
Tank water discharge	M	ND	ND

[a]ND = nondetectable toxicity/mutagenicity
L = low toxicity
M = moderate toxicity/mutagenicity

[b]Toxicity test

[c]Mutagenicity test

However, based on the total flowrate of each stream, the exhaust gas still poses a higher environmental risk relative to the waste water as indicated by the Weighted Discharge Severity (WDS).

5.2 BIOASSAY ANALYSIS

The Level 1 bioassay protocol includes testing for both health and ecological effects (reference 5-4). Bioassay results presented here are limited to health effects tests. These tests consist of (1) the Ames assay, based on the property of Salmonella typhimurium mutants to revert due to exposure to various classes of mutagens; (2) the cytotoxicity assay (CHO) of mammalian cells in culture to measure cellular metabolic impairment and death resulting from exposure to soluble toxicants; and (3) acute toxicity tests in live rodents (RAT) to identify in vivo toxic effects.

The results of these assays are summarized in table 5-2 for both the organic sorbent extract from the train and a tank water discharge sample. The responses varied from nondetectable to moderate toxicity and mutagenicity.

REFERENCES FOR SECTION 5

5-1. Herther, M. A. and L. R. Waterland, "SAM IA: A Rapid Screening Model for Environmental Assessment of Fossil Energy Process Effluents," Acurex Report TR-77-50D, March 1982.

5-2. Cleland, J. G. and G. L. Kingsbury, "Multimedia Environmental Goals for Environmental Assessment: Volumes I and II," EPA-600/7-77-136a,b, November 1977.

5-3. Kingsbury, G. L. et al., "Multimedia Environmental Goals for Environmental Assessment: Volumes III and IV," EPA-600/7-79-176a,b, August 1979.

5-4. Duke, K. M. et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment Biological Tests for Pilot Studies," EPA-600/7-77-043, April 1977.

APPENDIX A

TEST EQUIPMENT AND PROCEDURES

A.1 CONTINUOUS MONITORING SYSTEM AND CALIBRATION GASES

The residential heating system was set up in the Acurex combustion laboratory where hookup to the continuous air emissions monitoring system could easily be accomplished. A schematic of the gaseous emission monitoring system used for the test program is shown in figure A-1. In most applications, a sample from the flue gas is pulled through a heated filter where the particulates are removed. From the heated filter, the sample flows through a heated Teflon line to an oven. Additional filtration is performed in the oven and the sample is split into three streams. Calibration or zero gas is added at this point. From the heated oven, the three sample lines pass through a refrigerant dryer where the sample is condensed to a dew point of 2°C (35°F) and condensed water is removed. From the dryer, each sample gas passes through a pump and another filter prior to entering the continuous gas analyzers. Table A-1 lists the analyzers and the principle of operation for each of the gaseous emissions measured.

Because the exhaust gas of the furnace tested is already below its dew point, 24 to 32°C (75 to 90°F), a heated sample line and filter were not necessary. However, no modification to the sample conditioning system was made since the impact of heating the sample gas to approximately 121°C

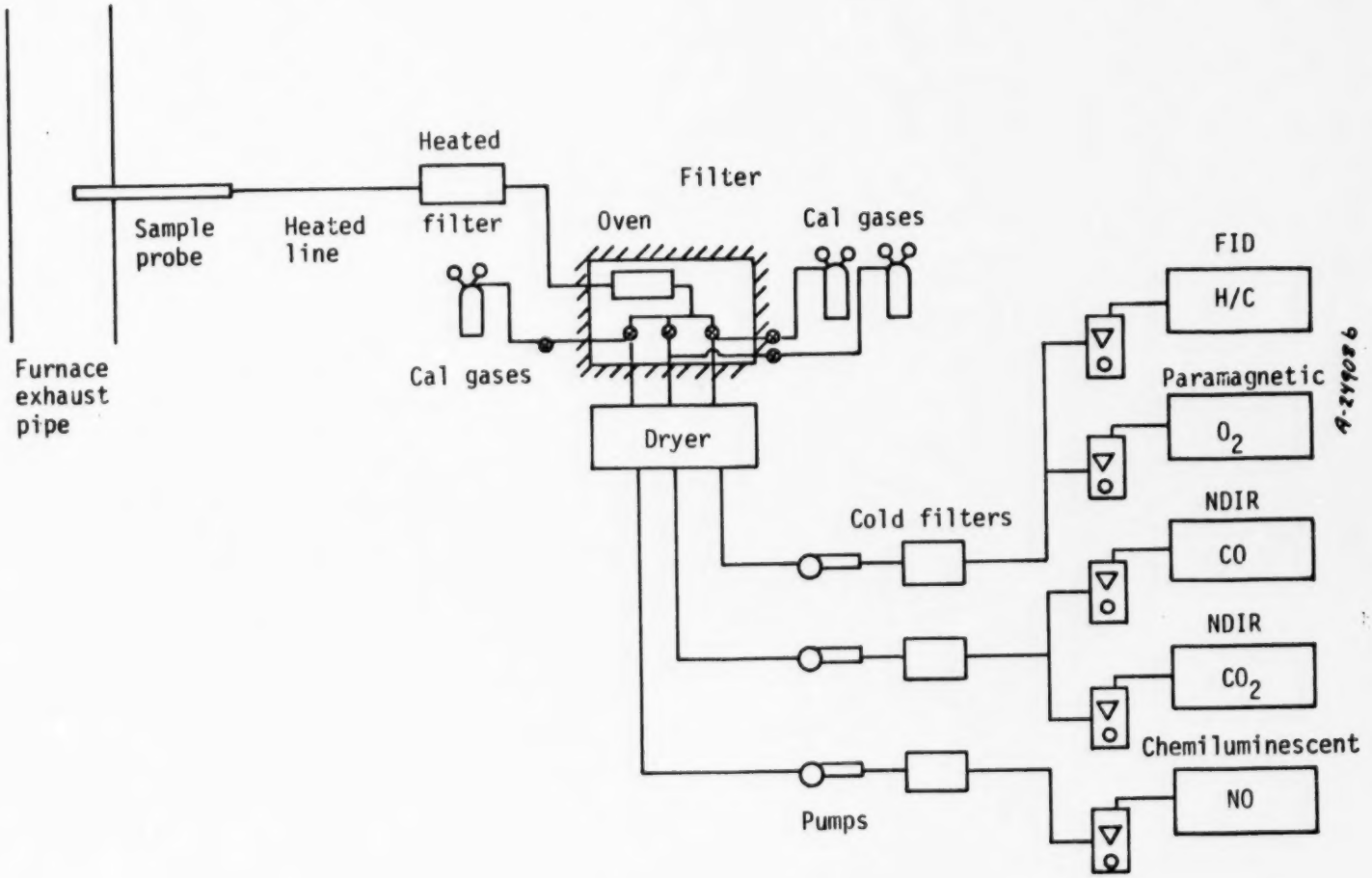


Figure A-1. Emission Monitoring System

Table A-1. Gaseous Emissions Monitoring Equipment

Instrument	Principle of Operation	Manufacturer	Models	Instrument Range
NO	Chemiluminescence	Air Modeling	32C	0-5 ppm 0-10 ppm 0-100 ppm 0-250 ppm 0-1000 ppm 0-5000 ppm
CO	Nondispersive Infrared (NDIR)	ANARAD	500R	0-1000 ppm
CO CO_2	Nondispersive Infrared (NDIR)	ANARAD	AR600R	0-15 percent 0-20 percent
O_2	Paramagnetic	Ethyl Intertech	Magnos 5T	0-5 percent 0-21 percent
UHC	Flame Ionization Detection (FID)	Ethyl Intertech	FID	0-100 ppm 0-300 ppm 0-1000 ppm 0-3000 ppm 0-10000 ppm 0-30000 ppm
Sample gas conditioner	Refrigerant dryer-condenser	Hankison	E-4G-SS	10 scfm

(250°F) on the concentration of water insoluble pollutants, such as CO and NO, was considered negligible.

A.2 PARTICULATE TESTS

Particulate mass emission tests were conducted in accordance with EPA Methods 1 through 5 of the Federal Register. The following sampling equipment was used:

- A 316 stainless steel sampling nozzle properly sized for isokinetic sampling
- A 0.9m (3 ft) heated stainless-steel-lined probe was used to isokinetically extract samples from the stack. The probe was kept at 121°C (250°F) as required by the EPA Method 5 and was equipped with a thermocouple to measure stack temperature and a calibrated S-type pitot tube to measure velocity pressure. However, because the gas velocity was extremely low for this source, a gas flow anemometer was used instead.
- A Teflon-coated stainless steel 142 mm (5.6 in.) filter holder
- An impinger train containing four glass bottles to collect moisture and condensable material escaping the filter
- A 4.7 l/s (10 cfm) carbon vane pump modified for very low leakage around the shaft
- A control module to monitor temperature, pressure, and flowrate throughout the sampling train. For this test, the orifice ΔH is indicated on a 0 to 1.5 kPa (0 to 6 in. W.G.) magnehelic gauge where the smallest division is 25 Pa (0.1 in. W.G.). The control module contains a Rockwell Model 415 dry gas meter to

measure the total volume of gas sampled to the nearest 0.14 l (0.005 ft^3). An orifice meter (after the dry gas meter) is used to measure the instantaneous flowrate through the sampling train to ensure sampling is done isokinetically.

Figure A-2 illustrates all these components of the High Volume Stack Sampler (HVSS) used for conducting the test program. The cyclone shown in the figure was not used in this test program.

A.2.1 Sample Collection

Sample collection took place on the 10 cm (4 in.) diameter uninsulated stack at approximately 1m (3 ft) from the furnace exit. Once the sample train was assembled, leak checks were performed before and after the test. Upon completion of the test, the probe and nozzle were cleaned and the impinger solutions were measured and recorded. The filter holder was sealed and brought to the cleanup laboratory for reclaiming. The particulate test was performed at a fixed location along the diameter of the stack because of its small size.

A.2.2 Sample Recovery

Figure A-3 illustrates the Method 5 sample recovery utilized to measure total particulate mass collected with the HVSS train. Solid particulate matter is defined as all particulate mass collected ahead of the filter impinger section: the filter, the probe, and the nozzle. Condensable particulate matter is obtained from gravimetric analysis of impinger liquids and impinger rinses. The impinger solutions are treated with ethyl ether to separate the organic matter from the liquid and solid samples.

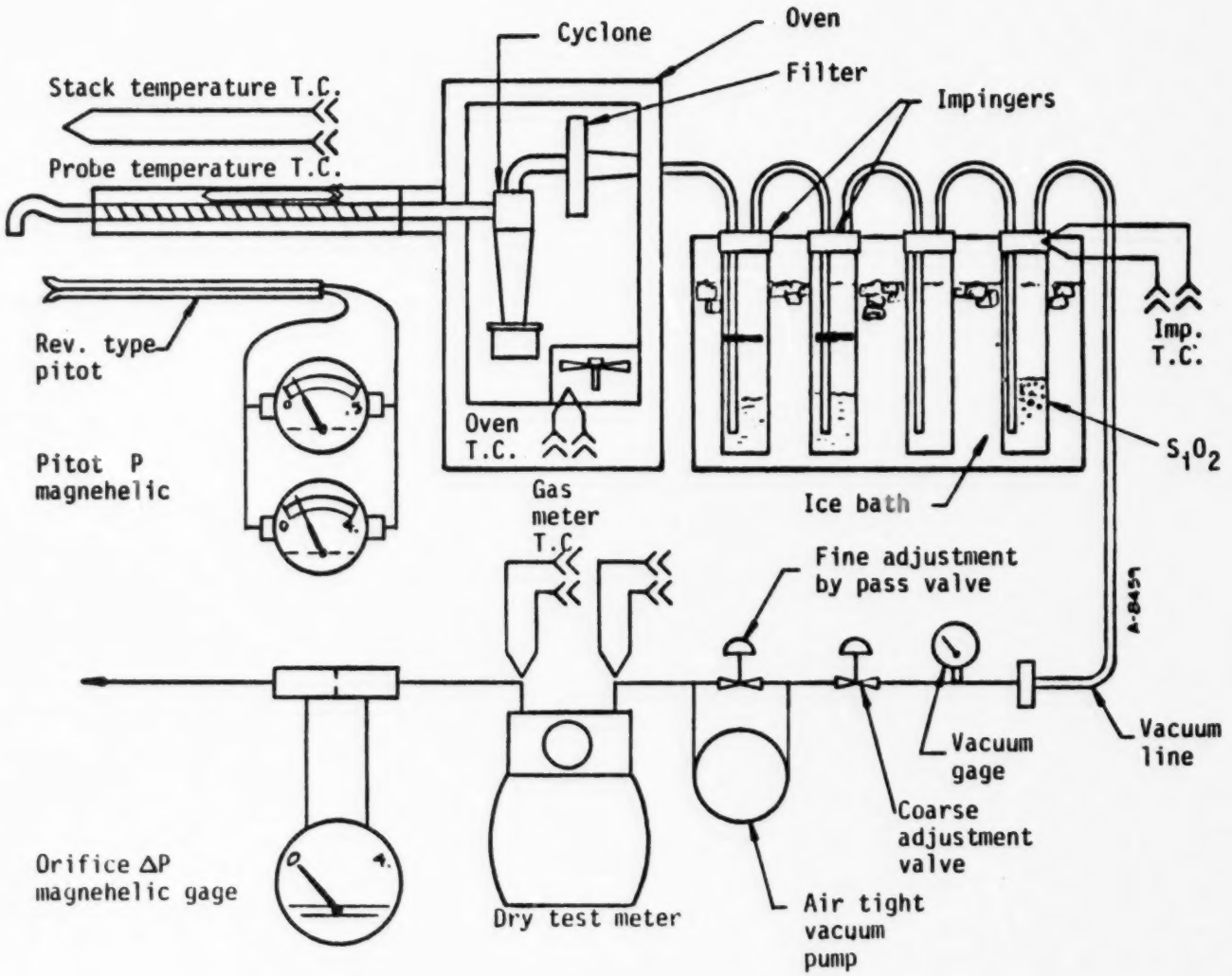


Figure A-2. Acurex High Volume Stack Sampler

FILTER
PROBE, NOZZLE AND FILTER WASH
IMPINGERS LIQUID
IMPINGER RINSE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
MEASURE VOLUME TO ±1 ml
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
EXTRACT WITH 3 x 25 ml ETHYL ETHER
ANALYZE FOR SULFATE
EXTRACT WITH 3 x 25 ml ETHYL ETHER
AQUEOUS LAYER
ORGANIC LAYER
SOLID
ORGANIC PHASE
EXTRACT WITH 3 x 25 ml CHLOROFORM
EXTRACT WITH 3 x 25 ml CHLOROFORM
COMBINE
AQUEOUS LAYER
ORGANIC LAYER
DISCARD SOLIDS
ORGANIC PHASE
FILTER THROUGH 47 mm TYPE A GLASS FILTER
DISCARD
COMBINE
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
EXTRACT WITH 100 ml DI WATER
DESICCATE AND WEIGH TO CONSTANT WEIGHT
AQUEOUS PHASE
ORGANIC PHASE
EVAPORATE ON STEAM BATH AND WEIGH TO CONSTANT WEIGHT
FILTER THROUGH A 47 mm TYPE A GLASS FILTER
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
NOTES
1) ALL WEIGHTS ARE TO NEAREST 0.01g
2) DESICCATE ALL SAMPLES FOR 24 HOURS PRIOR TO WEIGHING

Figure A-3. Sample Analysis Scheme for Particulate Sampling Train

A.3 SULFUR EMISSIONS

SO_2 and SO_3 emissions were measured using a modified HVSS sampler in accordance with EPA Method 8 procedures. In this procedure, a gas sample is extracted from a single point in the stack. In the impinger train for this method the first bottle contains isopropanol and the second contains hydrogen peroxide. A filter is placed between the two impinger bottles. Sulfuric acid mist and any vapor phase SO_3 is trapped in the isopropanol impinger. The backup filter traps any carryover mist. SO_2 is absorbed in the H_2O_2 impinger. After completion of a test the filter is rinsed with isopropanol; the rinse solution is added to the isopropanol impinger solution. Absorbed SO_3 and H_2SO_4 in the isopropanol and SO_2 in the H_2O_2 are determined separately by barium-thorin titration.

A.4 TRACE ELEMENTS AND ORGANIC EMISSIONS

Emissions of inorganic trace elements and organic compounds were sampled with the Source Assessment Sampling System (SASS). Designed and built for EPA's Industrial Environmental Research Laboratory for Level 1 environmental assessment, the SASS collects large quantities of gas and particulate samples required for subsequent analyses of inorganic and organic emissions as well as particle size measurement.

The SASS system, illustrated in figure A-4, is similar to the High Volume Stack Sampler (HVSS) system utilized for total particulate mass emission tests described in the previous section with the exception of:

- Particulate cyclones heated in the oven with the filter to 232°C (450°F)
- The addition of a gas cooler and organic sampling module
- The addition of necessary vacuum pumps

The cyclones were not employed in these tests.

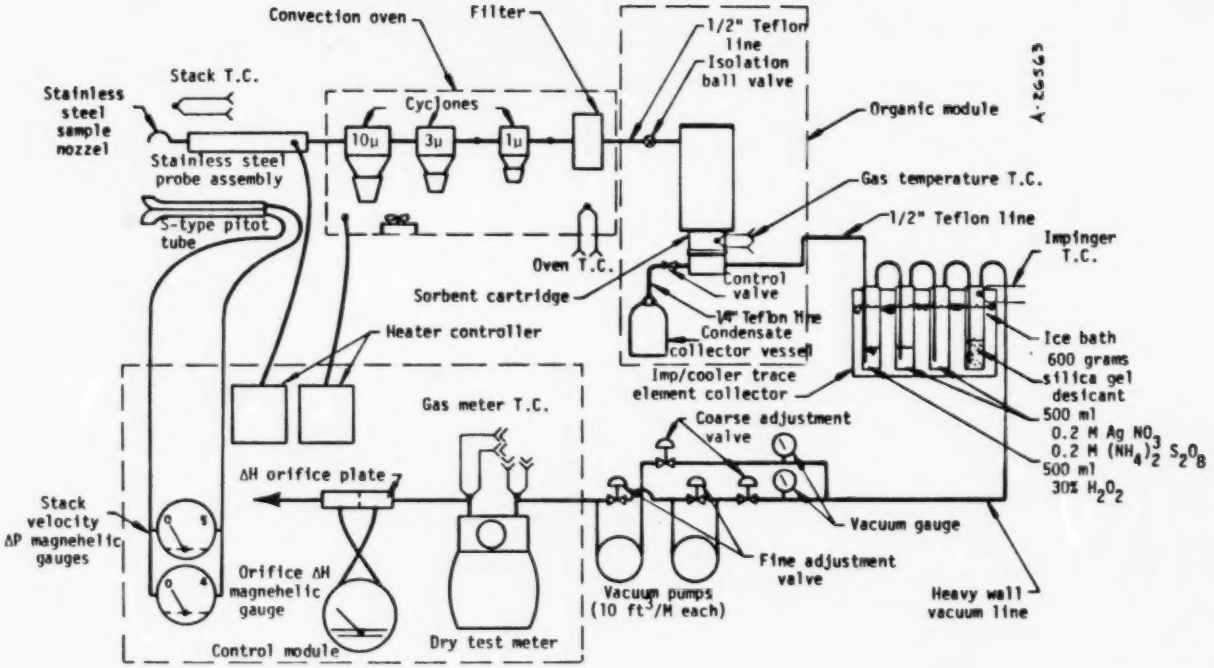


Figure A-4. Source Assessment Sampling Train Schematic

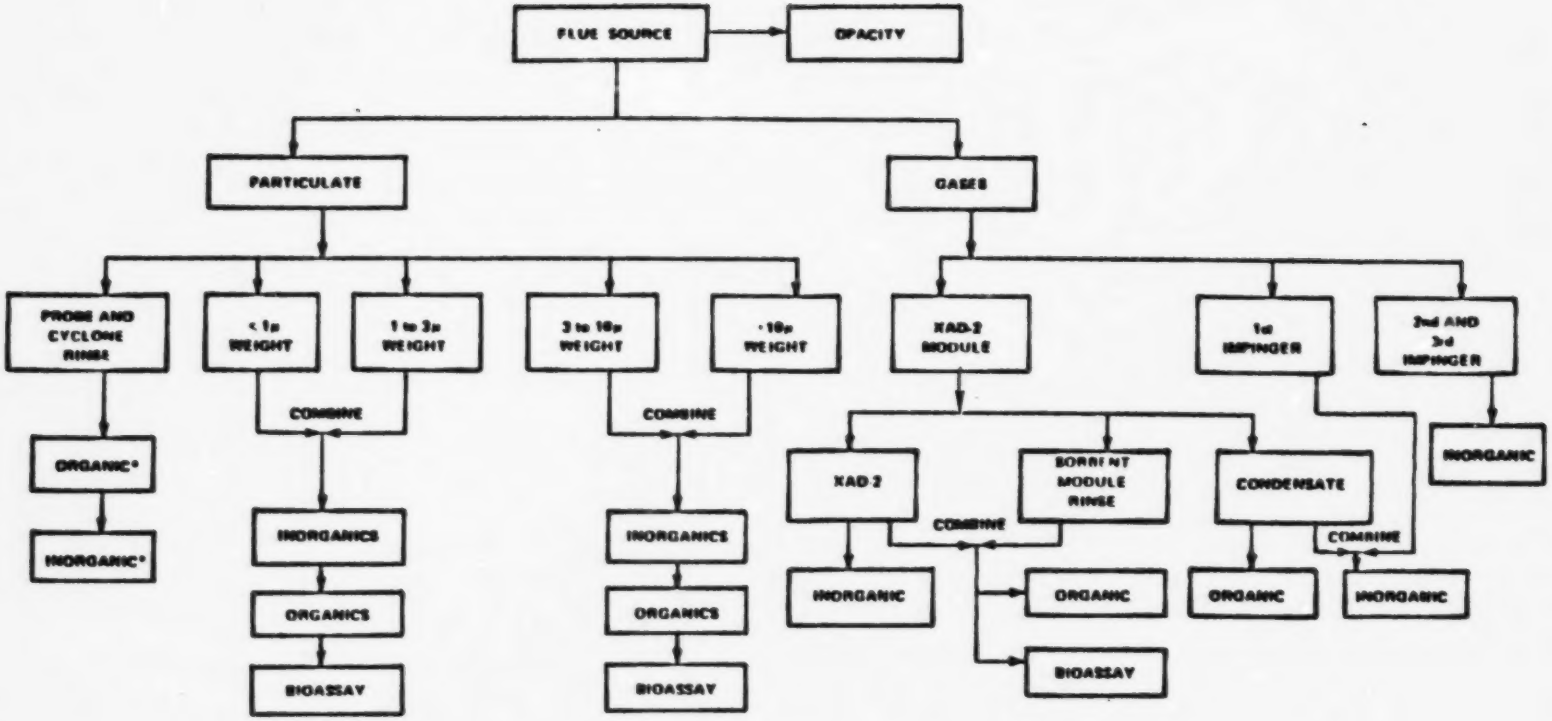
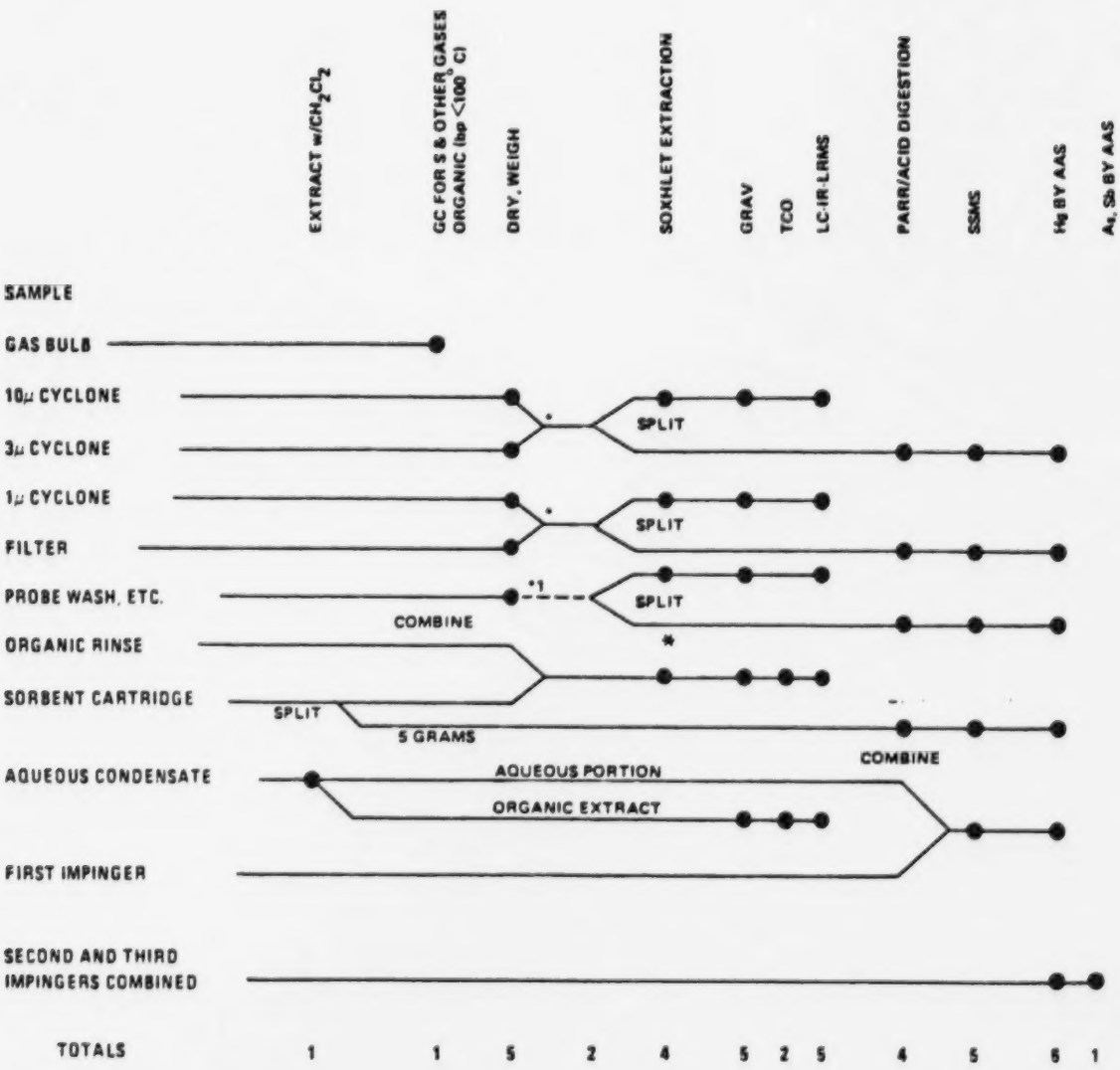


Figure A-5. Exhaust Gas Analysis Protocol

Reproduced from best available copy.



* If required, sample should be set aside for biological analysis at this point.

[1] This step is required to define the total mass of particulate catch. If the sample exceeds 10% of the total cyclone and filter sample weight proceed to analysis. If the sample is less than 10% of the catch, hold in reserve.

Figure A-6. Flue Gas Analysis Requirements of SASS Samples

Schematics outlining the sampling and analytical procedures using the SASS equipment are presented in figures A-5 and A-6.

Inorganic analyses of solid and liquid samples from the SASS train and fuels were performed by Spark Source Mass Spectroscopy (SSMS) for most of the trace elements. Atomic Absorption Spectrometry (AAS) was used for analyses of mercury (Hg), antimony (Sb), arsenic (As), and additional elements (nickel and copper) for which results by SSMS were deemed questionable. Anions were determined by ion chromatography. Quantitative information on total organic emissions was obtained by Total Chromatographable Organics (TCO) and by Gravimetry (GRAV) analyses. Gas Chromatography/Mass Spectroscopy (GS/MS) was used by Polycyclic Organic Matter (POM) and other organic species analysis of sample extracts. Figure A-7 illustrates the organic analysis methodology followed during the current program.

Passivation of the SASS train with 15 percent by volume HNO_3 solution was performed prior to equipment preparation and sampling to produce biologically inert surfaces. Detailed description of equipment preparation, sampling procedures, and sample recovery are discussed in reference A-1 and will not be repeated here. These procedures were followed in the course of the current test program.

A.5 C_1 - C_6 HYDROCARBON SAMPLING AND ANALYSIS

Acurex used a grab sampling procedure in order to obtain a sample of flue gas for C_1 - C_6 hydrocarbon analysis. Samples of the flue gas were extracted using a heated glass probe (figure A-8). The probe was attached to a heated 250-ml gas sampling bulb. The probe was maintained at 150°C (302°F) and the gas sampling bulb at 130°C (266°F). A diaphragm pump was used to pull samples through the probe and sampling

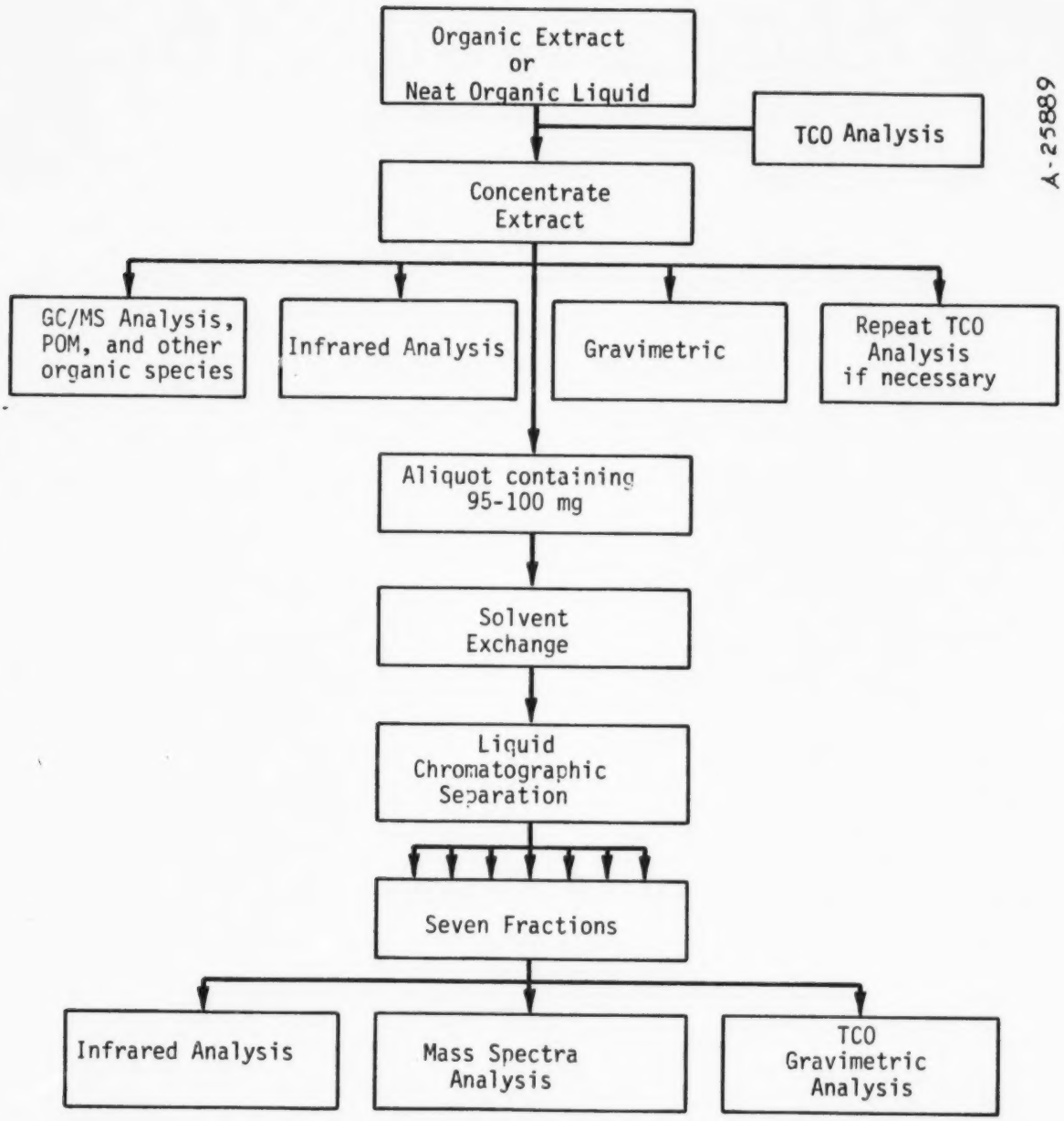
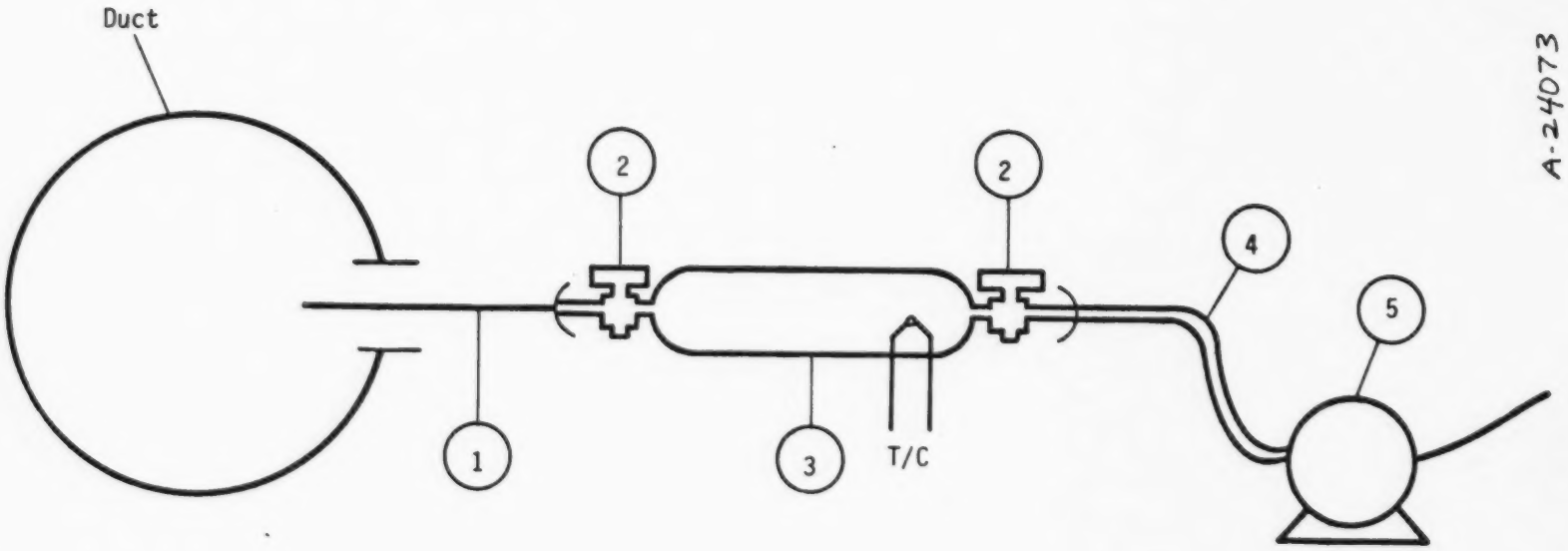


Figure A-7. Organic Analysis Methodology



1. Heated glass probe
2. Teflon stopcock
3. 250-ml heated glass gas sampling bulb
4. Tubing connection
5. Sample pump (1 cfm)

Figure A-8. C_1 - C_6 Hydrocarbon Sampling System

bulb. This purge was continued until all visual signs of condensation had disappeared. At that time, the back stopcock of the sampling bulb was closed and the pump was disconnected. Once the sampling bulb pressure had come to equilibrium with the stack pressure, the sample was sealed and transported to the onsite laboratory for analysis.

The gas sampling bulbs were equipped with a septum port. A gas-tight syringe was used to extract a measured amount of sample. Samples were analyzed on a Gas Chromatograph (GC) with a Flame Ionization Detector (FID). Both methane and nonmethane hydrocarbons were measured with each injection using a Varian Model 3700 GC with FID, automatic injection loop, and an automatic linear temperature programming capability, located at the Acurex laboratory in Mountain View, California. Table A-2 details the instrument specifications.

The GC was calibrated before and after each test in order to determine instrument drift. Blank samples were also run in order to quantify any sampling equipment interferences.

Sample data were recorded continuously on a strip chart recorder. After the detection of the methane peak, the column was back-flushed to the detector for analysis of the remaining nonmethane hydrocarbons. Each gas sampling bulb was analyzed several times to ensure a representative sample analysis.

REFERENCES FOR APPENDIX A

A-1. Lentzen, D. E. et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, October 1978.

Table A-2. Gas Chromatograph Specifications

Varian Model 3700 Gas Chromatograph:	
Sensitivity	1×10^{-12} A/mV at attenuation 1 and range 10^{-12} A/mV
Zero range	-10^{-11} to 10^{-9} A (reversible with internal switch)
Noise (inputs capped)	5×10^{-15} A; 0.5 μV peak to peak
Time constant	220 ms on all ranges (approximate 1 sec response to 99 percent of peak)
Gas required	Carrier gas (helium), combustion air, fuel gas (hydrogen)

APPENDIX B

TRACE ELEMENT CONCENTRATIONS

Symbols appearing in the tables:

DSCM	Dry standard cubic meter at 1 atm and 15°C
MCG	Microgram
PPM	Part per million by weight
SEC	Second
<	Less than
>	Greater than

Trace elements having concentrations less than the detectable limit or having a blank value greater than the sample value were given an arbitrary concentration of zero.

Detectability limits for the various SASS samples were the following:

- 10 + 3 μm cyclones -- <0.1 μg/g
- Filter -- <0.1 μg/g
- XAD-2 -- <0.1 μg/g
- Impinger and organic module concentrate -- <0.001 μg/ml
- Tank water -- <0.001 μg/ml

SECTION B.1

TRACE ELEMENT CONCENTRATIONS

(ppm)

M.A.N. RESIDENTIAL
LOW NOX

PPM

ELEMENT	FUEL OIL	TAP WATER BLANK	WATER TANK SAMPLE	FURNACE H2O OUTLET
ALUMINUM	>.100E+03	.400E-02	.0 E+00	.500E+00
ANTIMONY	.0 E+00	.0 E+00	.0 E+00	.200E-01
ARSENIC	.200E-01	.400E-02	.0 E+00	<.900E-02
BARIUM	.300E+00	.200E-01	.0 E+00	.0 E+00
BORON	.400E-01	<.100E-02	.0 E+00	.300E-01
BROMINE	.300E+00	.100E+00	.100E+00	.0 E+00
CADMIUM	.200E-01	.0 E+00	.0 E+00	.600E-02
CALCIUM	>.100E+03	.100E+02	>.100E+02	.0 E+00
CERIUM	.0 E+00	.0 E+00	.800E-02	.0 E+00
CESIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHLORINE	.700E+02	>.100E+02	.0 E+00	.0 E+00
CHROMIUM	.400E+00	.700E-01	.700E+00	.500E+00
COBALT	.400E-01	<.200E-02	.200E-01	.700E-01
COPPER	.500E+00	.200E-02	.505E+01	.480E+01
FLUORINE	.100E+01	.400E-02	.100E+00	.100E+00
GALLIUM	.200E-01	.900E-02	.0 E+00	.0 E+00
GERMANIUM	.0 E+00	.0 E+00	.200E-02	.0 E+00
IRON	.100E+02	.200E+00	>.100E+02	.700E+01
LANTHANUM	.0 E+00	.0 E+00	.100E-01	.0 E+00
LEAD	.200E+00	.100E-01	.700E-01	.600E-01
LITHIUM	.200E-01	.0 E+00	.0 E+00	.0 E+00
MAGANESE	.200E+00	.600E-02	.190E+00	.100E+00
MAGNESIUM	.200E+01	>.100E+02	.100E+00	.150E+01
MERCURY	<.100E+00	.0 E+00	.0 E+00	.0 E+00
MOLYBDENUM	.100E+00	.100E+00	.300E+00	.100E+00
NEODYMIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00
NICKEL	.100E+01	.300E-02	.100E+01	.700E+00
NIOBIUM	.0 E+00	.500E-02	.0 E+00	.0 E+00
PHOSPHORUS	.100E+01	.900E+00	.0 E+00	.400E+00
POTASSIUM	.700E+01	.500E-01	.0 E+00	.100E+01
RUBIDIUM	<.100E-01	<.200E-02	.0 E+00	.0 E+00
SCANDIUM	<.100E-01	.0 E+00	.400E-02	.100E-01
SELENIUM	.0 E+00	.0 E+00	.100E+00	.100E+00
SILICON	.250E+02	.200E+00	.0 E+00	.400E+01
SILVER	.0 E+00	.0 E+00	.300E-01	.0 E+00
SODIUM	.400E+01	.200E+00	.0 E+00	.0 E+00
STRONTIUM	.0 E+00	.200E-01	.200E-01	.0 E+00
SULFUR	.200E+00	.400E+00	>.100E+02	>.100E+02
TANTALUM	.0 E+00	.0 E+00	.0 E+00	<.400E-01
TELLURIUM	.200E+00	.0 E+00	.200E-01	.600E-02
THULIUM	.0 E+00	.200E-01	.0 E+00	.0 E+00
TIN	.300E-01	.0 E+00	.0 E+00	<.600E-02
TITANIUM	.500E+01	.100E+00	.200E+00	.100E+00
TUNGSTEN	.0 E+00	.0 E+00	0.200E-01	.0 E+00
VANADIUM	.200E-01	<.100E-02	.400E-02	.0 E+00
YTTRIUM	.200E-01	.0 E+00	.500E-01	<.200E+00
ZINC	.700E+00	.400E-01	>.100E+02	>.100E+02
ZIRCONIUM	.400E-01	.200E-01	.300E-01	.100E-01
CHLORIDE	.0 E+00	.0 E+00	.100E+01	.100E+01
NITRATE	.0 E+00	.0 E+00	.700E+01	.700E+01
SULFATE	.0 E+00	.0 E+00	.990E+03	.100E+04

M.A.N. RESIDENTIAL
LOW NOX

PPM

ELEMENT	FILTER + WASHES	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGER
ALUMINIUM	>.110E+06	.0 E+00	>.400E+00	.0 E+00
ANTIMONY	.0 E+00	.0 E+00	.0 E+00	<.300E-02
ARSENIC	.0 E+00	.0 E+00	.0 E+00	<.100E-01
BARIUM	.786E+04	.0 E+00	.0 E+00	.0 E+00
BORON	>.110E+06	.0 E+00	.200E-02	.0 E+00
BROMINE	.112E+03	.400E+00	.0 E+00	.0 E+00
CADMIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CALCIUM	>.110E+06	.0 E+00	.0 E+00	.0 E+00
CERIUM	.225E+03	.0 E+00	<.100E-02	.0 E+00
CESIUM	.0 E+00	.0 E+00	<.100E-02	.0 E+00
CHLORINE	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHROMIUM	.900E+03	.0 E+00	.700E-01	.0 E+00
COBALT	.225E+03	.0 E+00	.0 E+00	.0 E+00
COPPER	.337E+04	.0 E+00	.100E+00	.0 E+00
FLUORINE	.110E+05	.0 E+00	.200E+00	.0 E+00
GALLIUM	.110E+02	.0 E+00	.200E-02	.0 E+00
GERMANIUM	<.670E+02	.0 E+00	.0 E+00	.0 E+00
IRON	.560E+04	.0 E+00	.300E+00	.0 E+00
LANTHANUM	.225E+03	.0 E+00	.0 E+00	.0 E+00
LEAD	.225E+04	.0 E+00	.400E-01	.0 E+00
LITHIUM	.225E+03	.0 E+00	.300E-02	.0 E+00
MAGANESE	.225E+09	.0 E+00	.300E-01	.0 E+00
MAGNESIUM	.340E+05	.0 E+00	.500E+00	.0 E+00
MERCURY	.0 E+00	<.100E+00	<.100E-02	<.100E-02
MOLYBDENUM	.560E+03	.600E+00	.0 E+00	.0 E+00
NEODYMIUM	.110E+02	.0 E+00	.0 E+00	.0 E+00
NICKEL	.337E+03	.0 E+00	.200E+00	.0 E+00
NIOBIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00
PHOSPHORUS	.450E+04	.0 E+00	.0 E+00	.0 E+00
POTASSIUM	.0 E+00	.0 E+00	.100E+01	.0 E+00
RUBIDIUM	.0 E+00	.0 E+00	<.100E-02	.0 E+00
SCANDIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00
SELENIUM	.0 E+00	.0 E+00	.600E-02	.0 E+00
SILICON	>.110E+06	.0 E+00	.600E+00	.0 E+00
SILVER	.110E+02	.0 E+00	.0 E+00	.0 E+00
SODIUM	>.110E+06	.0 E+00	>.400E+01	.0 E+00
STRONTIUM	.450E+03	.0 E+00	.0 E+00	.0 E+00
SULFUR	.780E+05	.500E+01	>.100E+02	.0 E+00
TANTALUM	.0 E+00	.100E+00	<.200E-02	.0 E+00
TELLURIUM	.0 E+00	.0 E+00	.100E-01	.0 E+00
THULIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00
TIN	.225E+03	.0 E+00	.0 E+00	.0 E+00
TITANIUM	.112E+04	.0 E+00	.300E+00	.0 E+00
TUNGSTEN	.0 E+00	.0 E+00	.0 E+00	.0 E+00
VANADIUM	.225E+04	.0 E+00	.0 E+00	.0 E+00
YTTRIUM	.560E+02	.0 E+00	.0 E+00	.0 E+00
ZINC	.674E+04	.0 E+00	0.130E+00	.0 E+00
ZIRCONIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHLORIDE	.0 E+00	.0 E+00	.0 E+00	.0 E+00
NITRATE	.0 E+00	.0 E+00	.0 E+00	.0 E+00
SULFATE	.0 E+00	.0 E+00	.0 E+00	.0 E+00

M.A.N. RESIDENTIAL
LOW NOX

GAS CONCENTRATION
MCG/DSCM

ELEMENT	FILTER + WASHES	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGER	FURNACE OUTLET
ALUMINUM	> .544E+02	.0 E+00	> .168E+02	.0 E+00	> .712E+02
ANTIMONY	.0 E+00	.0 E+00	.0 E+00	< .511E-04	< .511E-04
ARSENIC	.0 E+00	.0 E+00	.0 E+00	< .170E-03	< .170E-03
BARIUM	.389E+01	.0 E+00	.0 E+00	.0 E+00	.389E+01
BORON	> .544E+02	.0 E+00	.839E-01	.0 E+00	> .545E+02
BROMINE	.554E-01	.168E+01	.0 E+00	.0 E+00	.174E+01
CADMIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CALCIUM	> .544E+02	.0 E+00	.0 E+00	.0 E+00	> .544E+02
CERIUM	.111E+00	.0 E+00	< .419E-01	.0 E+00	.111E+00<X<.153E+00
CESIUM	.0 E+00	.0 E+00	< .419E-01	.0 E+00	< .419E-01
CHLORINE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHROMIUM	.445E+00	.0 E+00	.294E+01	.0 E+00	.338E+01
COBALT	.111E+00	.0 E+00	.0 E+00	.0 E+00	.111E+00
COPPER	.167E+01	.0 E+00	.419E+01	.0 E+00	.586E+01
FLUORINE	.544E+01	.0 E+00	.839E+01	.0 E+00	.138E+02
GALLIUM	.544E-02	.0 E+00	.839E-01	.0 E+00	.893E-01
GERMANIUM	< .332E-01	.0 E+00	.0 E+00	.0 E+00	< .332E-01
IRON	.277E+01	.0 E+00	.126E+02	.0 E+00	.154E+02
LANTHANUM	.111E+00	.0 E+00	.0 E+00	.0 E+00	.111E+00
LEAD	.111E+01	.0 E+00	.168E+01	.0 E+00	.279E+01
LITHIUM	.111E+00	.0 E+00	.126E+00	.0 E+00	.237E+00
MAGANESE	.111E+06	.0 E+00	.126E+01	.0 E+00	.111E+06
MAGNESIUM	.168E+02	.0 E+00	.210E+02	.0 E+00	.378E+02
MERCURY	.0 E+00	< .421E+00	< .419E-01	< .170E-04	< .463E+00
MOLYBDENUM	.277E+00	.253E+01	.0 E+00	.0 E+00	.280E+01
NEODYMIUM	.544E-02	.0 E+00	.0 E+00	.0 E+00	.544E-02
NICKEL	.167E+00	.0 E+00	.839E+01	.0 E+00	.856E+01
NIOBIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
PHOSPHORUS	.223E+01	.0 E+00	.0 E+00	.0 E+00	.223E+01
POTASSIUM	.0 E+00	.0 E+00	.419E+02	.0 E+00	.419E+02
RUBIDIUM	.0 E+00	.0 E+00	< .419E-01	.0 E+00	< .419E-01
SCANDIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
SELENIUM	.0 E+00	.0 E+00	.252E+00	.0 E+00	.252E+00
SILICON	> .544E+02	.0 E+00	.252E+02	.0 E+00	> .796E+02
SILVER	.544E-02	.0 E+00	.0 E+00	.0 E+00	.544E-02
SODIUM	> .544E+02	.0 E+00	> .168E+03	.0 E+00	> .222E+03
STRONTIUM	.223E+00	.0 E+00	.0 E+00	.0 E+00	.223E+00
SULFUR	.386E+02	.211E+02	> .419E+03	.0 E+00	> .479E+03
TANTALUM	.0 E+00	.421E+00	< .839E-01	.0 E+00	.421E+00<X<.505E+00
TELLURIUM	.0 E+00	.0 E+00	.419E+00	.0 E+00	.419E+00
THULIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
TIN	.111E+00	.0 E+00	.0 E+00	.0 E+00	.111E+00
TITANIUM	.554E+00	.0 E+00	.126E+02	.0 E+00	.131E+02
TUNGSTEN	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
VANADIUM	.111E+01	.0 E+00	.0 E+00	.0 E+00	.111E+01
YTTRIUM	.277E-01	.0 E+00	.0 E+00	.0 E+00	.277E+01
ZINC	.334E+01	.0 E+00	0 .545E+01	.0 E+00	.879E+01
ZIRCONIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHLORIDE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
NITRATE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
SULFATE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00

MASS/HEAT INPUT — M.A.N. RESIDENTIAL LOW NOX — NG/J

ELEMENT	FUEL OIL	FURNACE H2O OUTLET	FURNACE OUTLET
ALUMINUM	> .224E+01	.110E-01	> .271E-01
ANTIMONY	.0 E+00	.441E-03	< .194E-07
ARSENIC	.449E-03	< .198E-03	< .648E-07
BARIUM	.673E-02	.0 E+00	.148E-02
BORON	.897E-03	.661E-03	> .207E-01
BROMINE	.673E-02	.0 E+00	.662E-03
CADMIUM	.449E-03	.132E-03	.0 E+00
CALCIUM	> .224E+01	.0 E+00	> .207E-01
CERIUM	.0 E+00	.0 E+00	.424E-04<X<.583E-04
CESIUM	.0 E+00	.0 E+00	< .160E-04
CHLORINE	.157E+01	.0 E+00	.0 E+00
CHROMIUM	.897E-02	.110E-01	.129E-02
COBALT	.897E-03	.154E-02	.424E-04
COPPER	.112E-01	.106E+00	.223E-02
FLUORINE	.224E-01	.220E-02	.526E-02
GALLIUM	.449E-03	.0 E+00	.340E-04
GERMANIUM	.0 E+00	.0 E+00	< .126E-04
IRON	.224E+00	.154E+00	.584E-02
LANTHANUM	.0 E+00	.0 E+00	.424E-04
LEAD	.449E-02	.132E-02	.106E-02
LITHIUM	.449E-03	.0 E+00	.903E-04
MAGANESE	.449E-02	.220E-02	.424E+02
MAGNESIUM	.449E-01	.331E-01	.144E-01
MERCURY	< .224E-02	.0 E+00	< .176E-03
MOLYBDENUM	.224E-02	.220E-02	.107E-02
NEODYMIUM	.0 E+00	.0 E+00	.207E-05
NICKEL	.224E-01	.154E-01	.326E-02
NIOBIUM	.0 E+00	.0 E+00	.0 E+00
PHOSPHORUS	.224E-01	.882E-02	.848E-03
POTASSIUM	.157E+00	.220E-01	.160E-01
RUBIDIUM	< .224E-03	.0 E+00	< .160E-04
SCANDIUM	< .224E-03	.220E-03	.0 E+00
SELENIUM	.0 E+00	.220E-02	.958E-04
SILICON	.561E+00	.882E-01	> .303E-01
SILVER	.0 E+00	.0 E+00	.207E-05
SODIUM	.897E-01	.0 E+00	> .846E-01
STRONTIUM	.0 E+00	.0 E+00	.848E-04
SULFUR	.449E-02	> .220E+00	> .182E+00
TANTALUM	.0 E+00	< .882E-03	.160E-03<X<.192E-03
TELLURIUM	.449E-02	.132E-03	.160E-03
THULIUM	.0 E+00	.0 E+00	.0 E+00
TIN	.673E-03	< .132E-03	.424E-04
TITANIUM	.112E+00	.220E-02	.500E-02
TUNGSTEN	.0 E+00	.0 E+00	.0 E+00
VANADIUM	.449E-03	.0 E+00	.424E-03
YTTRIUM	.449E-03	< .441E-02	.105E-04
ZINC	.157E-01	> .220E+00	.334E-02
ZIRCONIUM	.897E-03	.220E-03	.0 E+00
CHLORIDE	.0 E+00	.220E-01	.0 E+00
NITRATE	.0 E+00	.154E+00	.0 E+00
SULFATE	.0 E+00	.220E+02	.0 E+00

M.A.N. RESIDENTIAL
LOW NOX

MASS/HEAT INPUT ELEMENT	FILTER + WASHES NG/J	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGER	FURNACE OUTLET
ALUMINUM	> .207E-01	.0 E+00	> .638E-02	.0 E+00	> .27[illegible]E-0[illegible]
ANTIMONY	.0 E+00	.0 E+00	.0 E+00	< .194E-07	< .194E-07
ARSENIC	.0 E+00	.0 E+00	.0 E+00	< .648E-07	< .648E-07
BARIUM	.148E-02	.0 E+00	.0 E+00	.0 E+00	.148E-02
BORON	> .207E-01	.0 E+00	.319E-04	.0 E+00	> .207E-01
BROMINE	.211E-04	.641E-03	.0 E+00	.0 E+00	.663E-03
CADMIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CALCIUM	> .207E-01	.0 E+00	.0 E+00	.0 E+00	> .207E-01
CERIUM	.424E-04	.0 E+00	< .160E-04	.0 E+00	.424E-04<X<.583E-04
CESIUM	.0 E+00	.0 E+00	< .160E-04	.0 E+00	< .160E-04
CHLORINE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHROMIUM	.170E-03	.0 E+00	.112E-02	.0 E+00	.129E-02
COBALT	.424E-04	.0 E+00	.0 E+00	.0 E+00	.424E-04
COPPER	.635E-03	.0 E+00	.160E-02	.0 E+00	.223E-02
FLUORINE	.207E-02	.0 E+00	.319E-02	.0 E+00	.526E-02
GALLIUM	.207E-05	.0 E+00	.319E-04	.0 E+00	.340E-04
GERMANIUM	< .126E-04	.0 E+00	.0 E+00	.0 E+00	< .126E-04
IRON	.105E-02	.0 E+00	.479E-02	.0 E+00	.584E-02
LANTHANUM	.424E-04	.0 E+00	.0 E+00	.0 E+00	.424E-04
LEAD	.424E-03	.0 E+00	.638E-03	.0 E+00	.106E-02
LITHIUM	.424E-04	.0 E+00	.479E-04	.0 E+00	.903E-04
MAGANESE	.424E+02	.0 E+00	.479E-03	.0 E+00	.424E+02
MAGNESIUM	.640E-02	.0 E+00	.798E-02	.0 E+00	.144E-01
MERCURY	.0 E+00	< .160E-03	< .160E-04	< .648E-08	< .176E-03
MOLYBDENUM	.105E-03	.962E-03	.0 E+00	.0 E+00	.107E-02
NEODYMIUM	.207E-05	.0 E+00	.0 E+00	.0 E+00	.207E-05
NICKEL	.635E-04	.0 E+00	.319E-02	.0 E+00	.326E-02
NIOBIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
PHOSPHORUS	.848E-03	.0 E+00	.0 E+00	.0 E+00	.848E-03
POTASSIUM	.0 E+00	.0 E+00	.160E-01	.0 E+00	.160E-01
RUBIDIUM	.0 E+00	.0 E+00	< .160E-04	.0 E+00	< .160E-04
SCANDIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
SELENIUM	.0 E+00	.0 E+00	.958E-04	.0 E+00	.958E-04
SILICON	> .207E-01	.0 E+00	.958E-02	.0 E+00	> .303E-01
SILVER	.207E-05	.0 E+00	.0 E+00	.0 E+00	.207E-05
SODIUM	> .207E-01	.0 E+00	> .638E-01	.0 E+00	> .846E-01
STRONTIUM	.848E-04	.0 E+00	.0 E+00	.0 E+00	.848E-04
SULFUR	.147E-01	.801E-02	> .160E+00	.0 E+00	> .192E+00
TANTALUM	.0 E+00	.160E-03	< .319E-04	.0 E+00	.160E-03<X<.192E-03
TELLURIUM	.0 E+00	.0 E+00	.160E-03	.0 E+00	.160E-03
THULIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
TIN	.424E-04	.0 E+00	.0 E+00	.0 E+00	.424E-04
TITANIUM	.211E-03	.0 E+00	.479E-02	.0 E+00	.500E-02
TUNGSTEN	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
VANADIUM	.424E-03	.0 E+00	.0 E+00	.0 E+00	.424E-03
YTTRIUM	.105E-04	.0 E+00	.0 E+00	.0 E+00	.105E-04
ZINC	.127E-02	.0 E+00	0 .208E-02	.0 E+00	.334E-02
ZIRCONIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHLORIDE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
NITRATE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
SULFATE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00

M.A.N. RESIDENTIAL
LOW NOX

MASS/TIME MCG/SEC ELEMENT	FUEL OIL	FURNACE H2O OUTLET	FURNACE OUTLET
ALUMINUM	> .461E+02	.227E+00	> .558E+00
ANTIMONY	.0 E+00	.907E-02	< .400E-06
ARSENIC	.923E-02	< .408E-02	< .133E-05
BARIUM	.138E+00	.0 E+00	.305E-01
BORON	.185E-01	.136E-01	> .427E+00
BROMINE	.138E+00	.0 E+00	.136E-01
CADMIUM	.923E-02	.272E-02	.0 E+00
CALCIUM	> .461E+02	.0 E+00	> .426E+00
CERIUM	.0 E+00	.0 E+00	.872E-03<X<.120E-02
CESIUM	.0 E+00	.0 E+00	< .328E-03
CHLORINE	.323E+02	.0 E+00	.0 E+00
CHROMIUM	.185E+00	.227E+00	.265E-01
COBALT	.185E-01	.318E-01	.872E-03
COPPER	.231E+00	.218E+01	.459E-01
FLUORINE	.461E+00	.454E-01	.108E+00
GALLIUM	.923E-02	.0 E+00	.699E-03
GERMANIUM	.0 E+00	.0 E+00	< .260E-03
IRON	.461E+01	.318E+01	.120E+00
LANTHANUM	.0 E+00	.0 E+00	.872E-03
LEAD	.923E-01	.272E-01	.219E-01
LITHIUM	.923E-02	.0 E+00	.186E-02
MAGANESE	.923E-01	.454E-01	.872E+03
MAGNESIUM	.923E+00	.681E+00	.296E+00
MERCURY	< .461E-01	.0 E+00	< .363E-02
MOLYBDENUM	.461E-01	.454E-01	.220E-01
NEODYMIUM	.0 E+00	.0 E+00	.426E-04
NICKEL	.461E+00	.318E+00	.670E-01
NIOBIUM	.0 E+00	.0 E+00	.0 E+00
PHOSPHORUS	.461E+00	.181E+00	.174E-01
POTASSIUM	.323E+01	.454E+00	.328E+00
RUBIDIUM	< .461E-02	.0 E+00	< .328E-03
SCANDIUM	< .461E-02	.454E-02	.0 E+00
SELENIUM	.0 E+00	.454E-01	.197E-02
SILICON	.115E+02	.181E+01	> .623E+00
SILVER	.0 E+00	.0 E+00	.426E-04
SODIUM	.185E+01	.0 E+00	> .174E+01
STRONTIUM	.0 E+00	.0 E+00	.174E-02
SULFUR	.923E-01	> .454E+01	> .375E+01
TANTALUM	.0 E+00	< .181E-01	.330E-02<X<.395E-02
TELLURIUM	.923E-01	.272E-02	.328E-02
THULIUM	.0 E+00	.0 E+00	.0 E+00
TIN	.138E-01	< .272E-02	.872E-03
TITANIUM	.231E+01	.454E-01	.103E+00
TUNGSTEN	.0 E+00	.0 E+00	.0 E+00
VANADIUM	.923E-02	.0 E+00	.872E-02
YTTRIUM	.923E-02	< .907E-01	.217E-03
ZINC	.323E+00	> .454E+01	.688E-01
ZIRCONIUM	.185E-01	.454E-02	.0 E+00
CHLORIDE	.0 E+00	.454E+00	.0 E+00
NITRATE	.0 E+00	.318E+01	.0 E+00
SULFATE	.0 E+00	.454E+03	.0 E+00

M.A.N. RESIDENTIAL
LOW NOX

MASS/TIME MCG/SEC ELEMENT	FILTER + WASHES	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGER	FURNACE OUTLET
ALUMINUM	> .426E+00	.0 E+00	> .131E+00	.0 E+00	> .55AE+00
ANTIMONY	.0 E+00	.0 E+00	.0 E+00	< .400E-06	< .400E-06
ARSENIC	.0 E+00	.0 E+00	.0 E+00	< .133E-05	< .133E-05
BARIUM	.305E-01	.0 E+00	.0 E+00	.0 E+00	.305E-01
BORON	> .426E+00	.0 E+00	.657E-03	.0 E+00	> .427E+00
BROMINE	.434E-03	.132E-01	.0 E+00	.0 E+00	.136E-01
CADMIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CALCIUM	> .426E+00	.0 E+00	.0 E+00	.0 E+00	> .426E+00
CERIUM	.872E-03	.0 E+00	< .328E-03	.0 E+00	.872E-03<XC<.120E-02
CESIUM	.0 E+00	.0 E+00	< .328E-03	.0 E+00	< .328E-03
CHLORINE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHROMIUM	.349E-02	.0 E+00	.230E-01	.0 E+00	.265E-01
COBALT	.872E-03	.0 E+00	.0 E+00	.0 E+00	.872E-03
COPPER	.131E-01	.0 E+00	.328E-01	.0 E+00	.459E-01
FLUORINE	.426E-01	.0 E+00	.657E-01	.0 E+00	.108E+00
GALLIUM	.426E-04	.0 E+00	.657E-03	.0 E+00	.699E-03
GERMANIUM	< .260E-03	.0 E+00	.0 E+00	.0 E+00	< .260E-03
IRON	.217E-01	.0 E+00	.985E-01	.0 E+00	.120E+00
LANTHANUM	.872E-03	.0 E+00	.0 E+00	.0 E+00	.872E-03
LEAD	.872E-02	.0 E+00	.131E-01	.0 E+00	.219E-01
LITHIUM	.872E-03	.0 E+00	.985E-03	.0 E+00	.186E-02
MAGANESE	.872E+03	.0 E+00	.985E-02	.0 E+00	.872E+03
MAGNESIUM	.132E+00	.0 E+00	.164E+00	.0 E+00	.296E+00
MERCURY	.0 E+00	< .330E-02	< .328E-03	< .133E-06	< .363E-02
MOLYBDENUM	.217E-02	.198E-01	.0 E+00	.0 E+00	.220E-01
NEODYMIUM	.426E-04	.0 E+00	.0 E+00	.0 E+00	.426E-04
NICKEL	.131E-02	.0 E+00	.657E-01	.0 E+00	.670E-01
NIOBIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
PHOSPHORUS	.174E-01	.0 E+00	.0 E+00	.0 E+00	.174E-01
POTASSIUM	.0 E+00	.0 E+00	.328E+00	.0 E+00	.328E+00
RUBIDIUM	.0 E+00	.0 E+00	< .328E-03	.0 E+00	< .328E-03
SCANDIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
SELENIUM	.0 E+00	.0 E+00	.197E-02	.0 E+00	.197E-02
SILICON	> .426E+00	.0 E+00	.197E+00	.0 E+00	> .623E+00
SILVER	.426E-04	.0 E+00	.0 E+00	.0 E+00	.426E-04
SODIUM	> .426E+00	.0 E+00	> .131E+01	.0 E+00	> .174E+01
STRONTIUM	.174E-02	.0 E+00	.0 E+00	.0 E+00	.174E-02
SULFUR	.302E+00	.165E+00	> .328E+01	.0 E+00	> .375E+01
TANTALUM	.0 E+00	.330E-02	< .657E-03	.0 E+00	.330E-02<XC<.395E-02
TELLURIUM	.0 E+00	.0 E+00	.328E-02	.0 E+00	.328E-02
THULIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
TIN	.872E-03	.0 E+00	.0 E+00	.0 E+00	.872E 03
TITANIUM	.434E-02	.0 E+00	.985E-01	.0 E+00	.103E+00
TUNGSTEN	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
VANADIUM	.872E-02	.0 E+00	.0 E+00	.0 E+00	.872E-02
YTTRIUM	.217E-03	.0 E+00	.0 E+00	.0 E+00	.217E-03
ZINC	.261E-01	.0 E+00	0 .427E-01	.0 E+00	.688E-01
ZIRCONIUM	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
CHLORIDE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
NITRATE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00
SULFATE	.0 E+00	.0 E+00	.0 E+00	.0 E+00	.0 E+00

M.A.N. RESIDENTIAL
LOW NOX

FURNACE MASS BALANCE

IN = FUEL OIL OUT = EXHAUST GAS + FURNACE WATER

ELEMENT	TOTAL IN	TOTAL OUT	MASS BALANCE(OUT/IN)
ALUMINUM	.461E+02 <X	.784E+00 <X	*
ANTIMONY		.907E-02	*
ARSENIC	.923E-02	X<.408E-02	.0 E+00<X<.443E+00
BARIUM	.138E+00	.305E-01	.220E+00
BORON	.185E-01	.441E+00 <X	.239E+02 <X
BROMINE	.138E+00	.136E-01	.985E-01
CADMIUM	.923E-02	.272E-02	.295E+00
CALCIUM	.461E+02 <X	.426E+00 <X	*
CERIUM		.872E-03<X<.120E-02	*
CESIUM		X<.328E-03	*
CHLORINE	.323E+02		.0 E+00
CHROMIUM	.185E+00	.253E+00	.137E+01
COBALT	.185E-01	.326E-01	.177E+01
COPPER	.231E+00	.222E+01	.964E+01
FLUORINE	.461E+00	.154E+00	.333E+00
GALLIUM	.923E-02	.699E-03	.758E-01
GERMANIUM		X<.260E-03	*
IRON	.461E+01	.330E+01	.715E+00
LANTHANUM		.872E-03	*
LEAD	.923E-01	.491E-01	.532E+00
LITHIUM	.923E-02	.186E-02	.201E+00
MAGANESE	.923E-01	.872E+03	.945E+04
MAGNESIUM	.923E+00	.977E+00	.106E+01
MERCURY	X<.461E-01	X<.363E-02	*
MOLYBDENUM	.461E-01	.673E-01	.146E+01
NEODYMIUM		.426E-04	*
NICKEL	.461E+00	.385E+00	.834E+00
NIOBIUM			*
PHOSPHORUS	.461E+00	.199E+00	.431E+00
POTASSIUM	.323E+01	.782E+00	.242E+00
RUBIDIUM	X<.461E-02	X<.328E-03	*
SCANDIUM	X<.461E-02	.454E-02	.984E+00 <X
SELENIUM		.473E-01	*
SILICON	.115E+02	.244E+01 <X	.211E+00 <X
SILVER		.426E-04	*
SODIUM	.185E+01	.174E+01 <X	.943E+00 <X
STRONTIUM		.174E-02	*
SULFUR	.923E-01	.829E+01 <X	.898E+02 <X
TANTALUM		.330E-02<X<.221E-01	*
TELLURIUM	.923E-01	.601E-02	.651E-01
THULIUM			*
TIN	.138E-01	.872E-03<X<.359E-02	.633E-01<X<.260E+00
TITANIUM	.231E+01	.148E+00	.643E-01
TUNGSTEN			*
VANADIUM	.923E-02	.872E-03	.945E+00
YTTRIUM	.923E-02	.217E-03<X<.910E-01	.235E-01<X<.986E+01
ZINC	.323E+00	.461E+01<X<********	.143E+02<X<********
ZIRCONIUM	.185E-01	.454E-02	.246E+00
CHLORIDE		.454E+00	*
NITRATE		.318E+01	*
SULFATE		.454E+03	*

APPENDIX C

CONVERSION FACTORS

MULTIPLIERS TO CONVERT EMISSION FACTORS FROM g/kg TO OTHER UNITS FOR NO. 2 OIL[a]

To obtain emission factor in these units	Multiply emission factor in g/kg fuel by
Gaseous pollutants and particulate:	
kg/1000 l fuel	0.862
g/10^6 cal input	0.092
lb/1000 gal	7.194
lb/10^6 Btu input	0.051
Gaseous pollutants:[b]	
ppm at 3 percent O_2, dry	$\frac{1770}{MW}$
ppm at 0 percent O_2, dry	$\frac{2065}{MW}$
ppm at 12 percent CO_2	$\frac{1597}{MW}$
Particulates:	
lb/10^6 scf flue gas at 3 percent O_2	4.58
lb/10^6 scf flue gas at 0 percent O_2	5.27
lb/10^6 scf flue gas at 12 percent CO_2	4.13

[a] Typical no. 2 fuel oil having 33 API gravity
[b] MW = molecular weight of pollutant